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Université Mohamed Khider Biskra

Faculté des Sciences et de la Technologie

Département de Génie Electrique

Filière :Automatique

Option :Automatisme et Informatique Industrielle

Réf:

Mémoire de Fin d'Etudes
En vue de l'obtention du diplôme:

MASTER

Thème

Magnetic suspension by artificial intelligence

Présenté par :

Agli Imad Eddine

Soutenu le :4 octobre 2020

Devant le jury composé de :

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Messaoudi Abdelhamid

Avis favorable du Président du Jury

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Cachet et signature

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Thème

Magnetic suspension by artificial intelligence

Proposé par : Messaoudi Abdel Hamid
Dirigé par : Messaoudi Abdel Hamid

Abstract:

In this thesis, we studied a magnetic suspension system and his control by controlling the force of attraction and repulsion of the magnetic field, then detail the strategy of controlling this field and using classic controller to modify the magnetic field.

In an attempt to improve this strategy we use the fuzzy logic method, where we replace the classic controller (PID) with the fuzzy control.

Key words: Magnetic suspension, fuzzy logic.

Résumé:
Dans cette mémoire, nous avons étudié un système de suspension magnétique et son contrôle en contrôlant la force d'attraction et de répulsion du champ magnétique, puis détaillons la stratégie de contrôle de ce champ et l'utilisation d'un contrôleur classique pour modifier le champ magnétique.
Pour tenter d'améliorer cette stratégie, nous utilisons la méthode de logique floue, où nous remplaçons le contrôleur classique (PID) par le contrôle flou.
Mots clés : Suspension magnétique, logique floue.

ملخص :

في هذه المذكرة نقوم بدراسة عن نظام تعليق مغناطيسي و التحكم فيه من خلال التحكم في قوة الجذب و التنافر للحقل المغناطيسي ثم نقوم في بتفصيل استراتيجية التحكم في هدا الحقل و استعمال المعدلات التقليدية لتعديل الحقل المغناطيسي.

في محاولة لتحسين هده الاستراتجية نقوم باستعمال طريقة المنطق المضبب, حيث نقوم باستبدال المعدل التقليدي بالمعدل الضبابي.

كلمات مفاتيحة : التعليق المغناطيسي,المنطق الضبابي.

Dedication

Every challenging work need self effort as well as guidance of elders especially those who very close to your heart.

My humble effort I dedicate to my sweet and loving

Father & mother

Whose affection, love, encouragement and prayers of day and night make me able to get such success and honour.

Along with all hard working and respected teachers

Imad

Acknowledgment

I am grateful to my supervisor mr **Messaoudi Abdel Hamid** for his encouragement, his advice and for the precious time he devoted to me ...

I would also like to thank mr **Bencahbane Fateh** president of the jury also the member of the jury mrs **Mihi Asia** for the interest they show towards us for reading this thesis

I am grateful to all my teachers during my school years.

I am grateful all the people who facilitated the realization of this work

Summary

Chapter 1

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ABBREVIATION

FLC: Fuzzy logic controller

Op-amp: Operational amplifiers

Sens: Sensor

Act: Actuator

Symbols

$\vec{\mathrm{H}}$: Magnetic field [A/m].

$\vec{\mathrm{E}}$: Electric field [V/m].

$\vec{B}$: Magnetic induction [T].

ρ : Electric density [C/m3].

$\vec{D}$: Electric induction [C/m2].

$\vec{\mathrm{J}}$: Represents the current density.

σ : Electrical conductivity [s.m^{-1}],

μ : Magnetic permeability [H .m^{-1}],

ε : Permittivity [F .m^{-1}],

v: Magnetic reluctivity [m. .H^{-1}]

L: Inductance (H).

R: Resistance (Ω).

Fm: The magnetic force depends on the current (N/kg)

U: Voltage (V).

F: The magnetic force

g: The gravity (m/s^2).

m: The mass (g).

I: Current (A).

General introduction

The Magnetic suspension System serves as a simple model of devices that have become more popular in recent years such as Maglev trains and magnetic bearings. Maglev trains are recently tested and some lines are already available for example in Shanghai. Magnetic bearings are used in turbines for the same reason as Maglev trains are being built, which is low friction in the bearing itself. Already many turbines are in commercial used where the rotating shaft is levitated with magnetic force. Some other magnetic bearing applications include pumps, fans and other rotating machines. [1]

The magnetic levitation systems are appealing for their additional possibility of active vibration damping. This can be done by implementing different control algorithms without any hardware modification to the mechanical parts of the whole system. The Maglev unit allows for the design of different controllers and test in real time using Matlab and Simulink environment.

Fuzzy logic controller (FLC) is an attractive alternative to existing classical or modern controllers for designing the nonlinear control systems. It does not require system models or complex mathematical equations describing the relationship between inputs and outputs. Fuzzy rules are very easy to learn and can be implement, even by non-experts. It typically takesonly a few rules to describe systems that may require several lines of conventional software codes, which reduce the design complexity. Although PID control is a proficient technique for handling non-linear systems but modeling these systems is often troublesome and sometimes impossible using the laws of physics. Therefore, the use of a classical controller is not suitable for nonlinear control application. Alternatively, Fuzzy Logic Control well suited for processes that are too complex for analysis by conventional techniques or when the available sources of information are interpreted qualitatively, inexactly, or uncertainly.[2]

This work will be divided into four parts.

In the **first chapter**, we explained generalities about magnetic suspension, including the types and applications as well as some mathematical equation.

In the **second chapter** we talked about one of the most effective control methods that is fuzzy logic, which based on artificial intelligence.

In the **third Chapter**, we explained magnetic suspension system modelling and methods of controlling a magnetic suspension system.

The **fourth chapter** is related to releasing a magnetic suspension system, including an explanation of some important electrical components.

We finish by a conclusion and. perspectives of our work.

Chapter 1

Generalities of magnetic suspension

1.1 Introduction

Magnetic suspension is a method to levitate an object with no support other than magnetic fields. Magnetic force is used to counteract the effects of the gravitational force and any other forces.Lifting forces are the primary issues involved in magnetic suspension: providing an upward force sufficient to counteract gravity, and stability: ensuring that the system does not spontaneously slide or flip into a configuration where the lift is neutralized.

Levitation based on the magnetic phenomenon is probably the most common principle of levitation. Its strengths remain low cost, ease of implementation and even robustness. In addition, magnetic levitation comes in many different forms making its use all the more attractive. These various forms are the result of researchers' investigations to circumvent the impossibility imposed by Earnshaw's theorem.

Magnetic levitation is used for maglev trains, contactless melting, magnetic bearings and for product display purposes [3][4].

1.2 Definition

Magnetic suspension of weight is based on the attraction orrepulsion between sets of current-carrying wires, or on the attraction or repulsion of ferromagnetic materials to magnets. Ferromagnetic objects can be suspended by a magnetic fieldbut unfortunately not stably, except in very specialized cases.

A servo system is needed to automatically control the magnetic field so that the field is decreased as the object approaches a suspending magnet and increased as it recedes.

1.3 History [4]

- 1839 Earnshaw's theorem showed electrostatic levitation cannot be stable.
- 1913 Emile Bachelet awarded a patent in March 1912 for his “levitating transmitting apparatus” (patent no. 1,020,942) for electromagnetic suspension system
- 1933 Super Diamagnetism Walther Meissner and Robert Ochsenfeld (the Meissner effect)
- 1934 Hermann Kemper “monorail vehicle with no wheels attached.” Reich Patent number 643316
- 1939 Braunbeck’s extension showed that magnetic levitation is possible with diamagnetic materials
- 1939 Bedford, Peer, and Tonks aluminum plate placed on two concentric cylindrical coils shows 6-axis stable levitation
- 1961 James R. Powell and BNL colleague Gordon Danby electrodynamic levitation using superconducting magnets and "Null flux" figure 8 coils.
- 1970s Spin stabilized magnetic levitation Roy M. Harrigan
- 1974 Magnetic river Eric Laithwaite and others
- 1979 transrapid train carried passengers
- 1981 First single-tether magnetic levitation system exhibited publicly
- 1984 Low speed maglev shuttle in Birmingham Eric Laithwaite and others
- 1997 Diamagnetically levitated live frog Andre Geim
- 1999 Inductrack permanent magnet electrodynamic levitation (General Atomics)
- 2000 The first man-loading HTS maglev test vehicle “Century” in the world was successfully developed in China.
- 2005 homopolar electrodynamic bearing

1.4 Stability

1.4.1 Earnshaw theorem

Earnshaw in 1839 has published his theorem. He demonstrates that a polarized particle immersed in an electrostatic field cannot find an equilibrium positionstable. Since then, this theorem has been extended to various magnetic bodies. Jérôme Delamare [5], in his thesis explained how we can have or not, the stability during the levitation of magnetic bodies such as permanent magnets, ferromagnetics, diamagnetics and conductors. From his study, we can draw the following conclusions:

If a magnet is immersed in a static field, the study of stability through stiffness, confirms that at least one of the three axes of translation of the magnet will be unstable. Therefore, it is impossible to achieve a stable suspension based solely on magnets. These properties remain valid for coils traversed by a constant current because they are then equivalent to magnets [3]

Earnshaw's theorem proves that it is impossible for a static system to stably levitate against gravity using only paramagnetic materials.

The more simple example of levitate with two simple dipole magnets repelling is unstable, because of the top magnet can slide sideways, or flip over, and it turns out that no configuration of magnets can produce stability. But, a servo system, the use of diamagnetic materials, superconduction, or systems involving eddy currents allow stability to be achieved.

In some cases the lifting force is provided by magnetic levitation, but stability is provided by a mechanical support bearing little load. This is termed pseudo-levitation

1.4.2 Static stability

Static stability means that any small displacement away from a stable equilibrium causes a net force to push it back to the equilibrium point.

1.4.3 Dynamic stability

Dynamic stability occurs when the levitation system is able to damp out any vibration-like motion that may occur [4].

1.5 Classification of magnetic levitations

To achieve successful levitation and control of all axes we can use a combination of permanent magnets and electromagnets or superconductors or attractive and repulsive magnetic fields.

1.5.1 Active magnetic levitation (electromagnetic levitation)

Active bearings are electromagnets whose current is controlled to maintain the moving part of the magnetic circuit in a fixed position. They need a supply of power to function. To power each of the actuators constituting an active bearing, a power supply, a control and a position sensor are required [5].

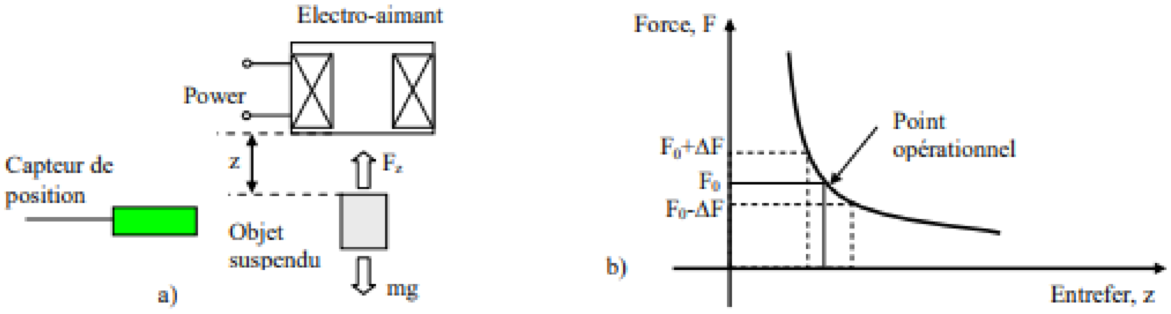


Figure 1.1 : Principle of electromagnetic suspension a) Physical configuration b) Characteristic (Force-distance)

The fundamental disadvantage of these types of suspensions is instability (Earnshaw's theorem). Because of this, special solutions have often been resorted to.

1.5.2 Magnetic levitation using the LC circuit

For Active magnetic levitationan external sensor is used to measure the distance or air gap between the suspended body and the electromagnet, unlike the implicit method, we take advantage of the variation in impedance due to the distance or approaching the suspended object to create a resonant circuit using a capacitor already existing in the electrical circuit (Figure 1.2). The operating point must coincide with the upward slope of the current resonance curve in order to be able to attract it. The shape of the force in Figure 1.2 is that of the force without a resonant circuit. The actual force exerted on the object is proportional to the square of the current F = h (i2) [3].

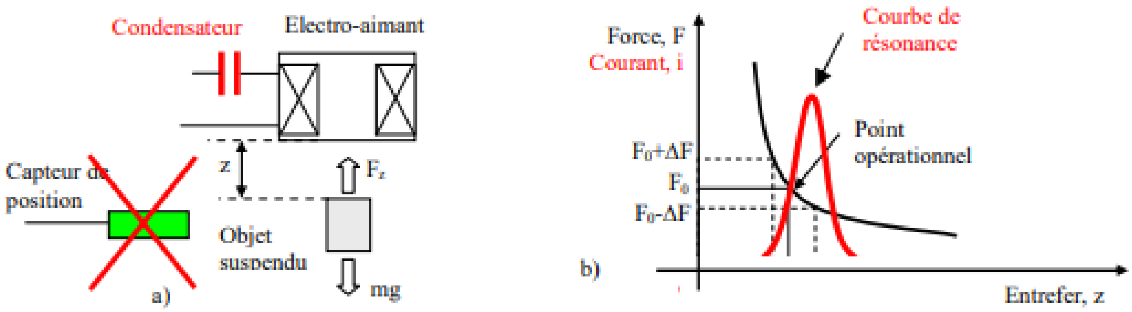


Figure 1.2 Principle of the resonant circuit electromagnetic suspension. a) Physical configuration b) Characteristic (Force-distance)

1.5.3 Superconducting levitation

Another method to achieve stable levitation is to use magnetic bodies with which Earnshaw's theorem can be easily circumvented. These are superconducting materials.

In the literature, the researchers have described that superconducting levitation takes place in two different forms. The first uses an effect specific to superconductors: the trapping of magnetic flux in the mixed state, and the second concerns the creation of repulsive forces between superconducting magnets and currents induced - by movement - in conductive plates. This second principle is the most widely used, especially in the field of passenger transport [3].

Figure 1.3 : A magnet floats above a superconductor

1.5.4 Electrodynamics levitation with alternating fields

The electrodynamic principle is based on the generation of repulsive forces due to induced currents (Lenz's law). This type of electrodynamic levitation is better suited to superconductors which are able to provide intense fields compared to normal conductors (copper, aluminum….). The cooling processes and the cost of the superconductors themselves often lead us to seek alternative solutions. However, to have currents induced in conductive objects, it suffices to place them near the copper coils supplied byvariable voltage or current sources.

The best example of this technique is that of a copper disc floating above a coil on display at the “Palais de la Découverte” in Paris (Figure 1.4), [3].

Figure1.4 :Electrodynamics levitation by alternating current

1.5.5 Levitation stabilized by the gyroscopic effect

There is a way to obtain the levitation of an object with only two magnets .For this it is not useful to have an intense field, a superconductor or induced currents. We just use the gyroscopic effect. This is how we can find on the market, tops capable of spinning for a few minutes at several centimetres above a magnetic base [Figure 1.5][5].

Figure 1.5 : Spinning top Levitron

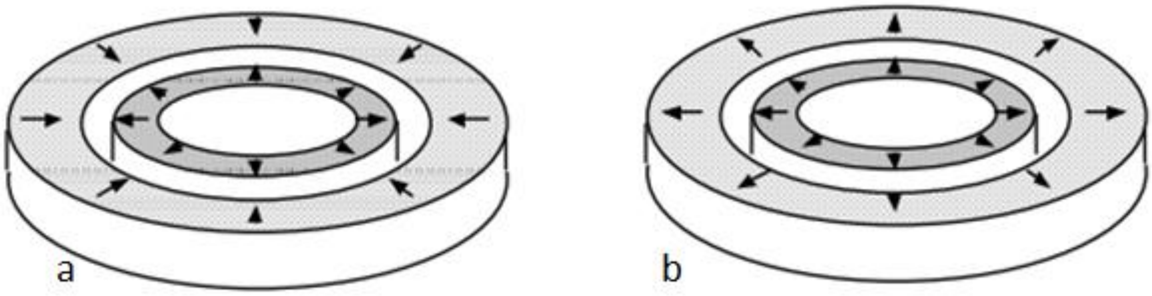
Unfortunately, this method of suspensions and levitations, have been found to be difficult to implement in practice, due to the low efficiency and load capacity.

1.5.6 Passive magnetic suspensions

Passive magnetic bearings are the simplest to make. Their operation does not require any outside energy (unlike active magnetic bearings), or cooling (unlike superconducting bearings). However, they cannot be used alone for reasons of stability. Passive magnetic bearings must therefore be associated with a mechanical system (rolling, hydrodynamic bearing, needle thrust, etc.) or with another type of magnetic bearing. There are two types of passive magnetic bearings: permanent magnet bearings and variable reluctance bearings [3].

1.5.7 Permanent magnet bearings

They consist of at least two rings of interacting permanent magnets, one of the rings being fixed while the other is integral with the rotor. Depending on the magnetization directions of the two rings, it is possible to obtain, with the same geometry, either a centering device or a



stop [6].

Figure 1.6 :Permanent magnet : a) centering device, b) stopper

1.5.8 Variable reluctance bearings

Here we are also dealing with passive systems. They therefore do not need any external power source to operate. Although they may include magnets, these bearings do not operate on a principle of direct interaction between magnets. They are made up of two separate magnetic circuits. One of the circuits is linked to the rotor while the other is fixed to the stator (Figure 1.7) [6].

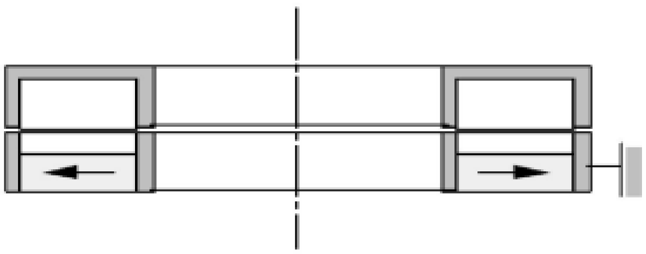


Figure 7 : Variable reluctance centering device

1.6 Fundamental equations in electromagnetism

The electromagnetic phenomena we study within levitation devices are subject to Maxwell's equations and the equations characteristic of materials. These equations are old concepts in physics [7].

1.6.1 Differential form of Maxwell's equations

$\vec{\boldsymbol{V}} \cdot \vec{\boldsymbol{D}} = \rho$ **(Maxwell Gauss equation)** **Equa1.1**

$\vec{\boldsymbol{\nabla}} \boldsymbol{\Lambda} \vec{\mathbf{E}} = -\frac{\partial \vec{\mathbf{B}}}{\partial \mathbf{t}}$**(Maxwell-Faraday equation)** **Equa1.2**

$\vec{\boldsymbol{\nabla}} \cdot \vec{\boldsymbol{B}} = \mathbf{0}$ **(Flow conservation equation)** **Equa1.3**

$\vec{\boldsymbol{\nabla}} \wedge \vec{\mathbf{H}} = \vec{\mathbf{J}}$**(Maxwell-Ampere equation)** **Equa1.4**

Which:

- $\vec{\mathrm{H}}$: Magnetic field [A/m].
- $\vec{\mathrm{E}}$: Electric field [V/m].
- $\vec{B}$: Magnetic induction [T].
- ρ : Electric density [C/m^3].
- $\vec{D}$: Electric induction [C/m^2].
- $\vec{\mathrm{J}}$: Represents the current density.

These equations are not sufficient to solve the electromagnetic problems, it is necessary to add to them relations which translate the behavior of the studied materials:

$\vec{\boldsymbol{B}} = \mu \vec{\mathbf{H}}Or\vec{\boldsymbol{H}} = \boldsymbol{v}\boldsymbol{B}$ **Equa1.5**

$\vec{\boldsymbol{D}} = \varepsilon \vec{\mathbf{E}}$ **Equa1.6**

$\overrightarrow{\mathbf{J}\,\mathbf{c}} = \boldsymbol{\sigma} \vec{\boldsymbol{E}}$ **Equa1.7**

Where:

σ : Electrical conductivity [s.m^{-1}],
μ : Magnetic permeability [H .m^{-1}],
ε : Permittivity [F .m^{-1}],
v:Magnetic reluctivity [m. .H^{-1}]

Equation (1.6) defining the dielectric characteristic and equation (1.7) defining the conductance property. But in a superconducting medium the relation between the electric field and thedensity of the electric current is nonlinear, which mean:

$$\overrightarrow{\mathrm{J\,c}} = \sigma(\vec{\mathrm{E}})\vec{\mathrm{E}}. \qquad \textbf{Equa1.8}$$

1.7 Application

Known uses of magnetic levitation include maglev trains, contactless melting, magnetic bearings and for product display purposes. Moreover, recently magnetic levitation has been approached in the field of microrobotics.The main applications are as follows:

- **Space:**The main application of magnetic suspensions in space relates to the implementation of flywheels to stabilize a satellite or to store energy. Magnetic bearings are also used in some shooting devices [6][7].

- **Maglev transportation:** Maglev, or magnetic levitation, is a system of transportation that suspends (Figure 1.8) [3].

Figure 1.8 : Magnetic suspension trains

- **Magnetic bearings :** Magnetic bearings,Flywheels,Centrifuges , Magnetic ring spinning

- **Machining:**Magnetic suspensions allowed to equip machining spindles and rotate cutting tools and it's provide provide great precision in rotation during machining(Figure 1.9).

Figure 1.9 : Milling cutter on magnetic bearings

- **Microrobotics :** In the field of microrobotics, strategies which exploit magnetic levitation have been investigated. In particular, it has been demonstrated that through such a technique, control of multiple microscale-sized agents within a defined workspace can be achieved. Several research studies report the realization of different custom setups to properly obtain the desired control of microrobots. In Philips laboratories in Hamburg a custom clinical scale system, integrating both permanent magnets and electromagnets, was used to perform magnetic levitation and 3D navigation of a single magnetic object [3].

- **The turboexpanders:** These are fast machines allowing the expansion of the gases. They are used in treatment, cooling, purification, separation or liquefaction operations. These machines are generally powerful and fast: from 10,000 to 50,000 rpm and a few hundred KW or several MW [5].

- **Turbomolecular pumps:** They make it possible to obtain a very high vacuum thanks to a turbine rotating at high speed (Figure 1.10). The vacuum obtained can reach 10-10 mbar. Magnetic bearings are used in turbomolecular pumps because they allow high speeds (100,000 rpm) to be reached without polluting the surrounding atmosphere with a lubricant [5].

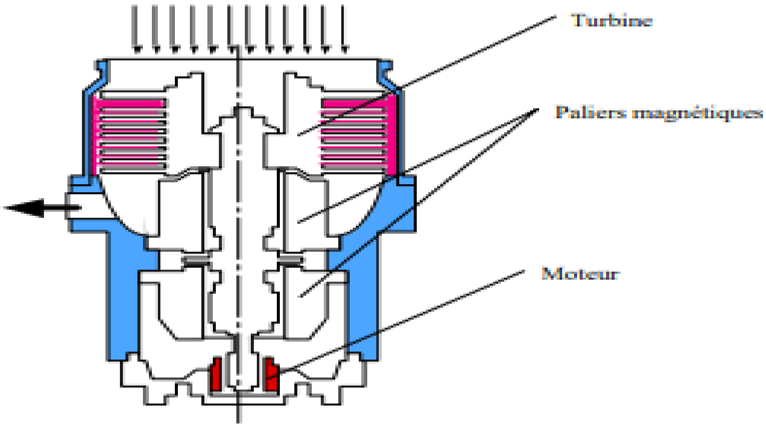


Figure 1.10 : Turbomolecular pump on magnetic suspension

- **Centrifuges**: because of their extremely high speed of rotation, they allow the separation of substances of different densities. They make it possible to enrich uranium at a rate that few other methods can achieve. The interest of the magnetic bearing comes from the fact that it makes it possible to reach high speeds while being compatible with the surrounding environment. Essentially passive bearings are used for this application.

1.8 Conclusion

In this chapter, we have presented a general study on magnetic suspension and the most important mathematical equations that we need to study a magnetic system. Also,we have presentedthe different types of magnetic suspension, as well as its different uses.In the next chapter, we will introduce the Fuzzy logic.

2 Chapter 2

Introduction to fuzzy logic

2.1 Introduction

Fuzzy logic has emerged as a very powerful tool in dealing with complex problems. Recently the role of inference in handling uncertainty in engineering applications is gaining importance. Engineers and scientists are generally confronted with problems which are impossible to solve numerically using traditional mathematical rules [8]. By making use of fuzzy logic, one can characterize and control a system whose model is not known or is ill-defined [9]. Fuzzy theory has the capability to capture the impreciseness of linguistic terms in statements of natural language. This provided with a greater capability to model human common-sense reasoning and decision making [10].

Fuzzy logic is an extension of Boolean logic by Lotfi Zadeh in 1965 based on the mathematical theory of fuzzy sets, which is a generalization of the classical set theory. By introducing the notion of degree in the verification of a condition, thus enabling a condition to be in a state other than true or false, fuzzy logic provides a very valuable flexibility for reasoning, which makes it possible to take into account inaccuracies and uncertainties. [11]

2.2 Transition From Boolean To Fuzzy

Fuzzy logic can be viewed as the superset of Boolean logic. In Boolean logic, each element either belongs to or does not belong to a set. If an element is a member of a given set, Boolean logic will return a 'ONE' (representing complete membership) else a 'ZERO' (representing non-membership) will be returned [8]. The figure 2.1 gives representation of logic or conventional set and fuzzy set.

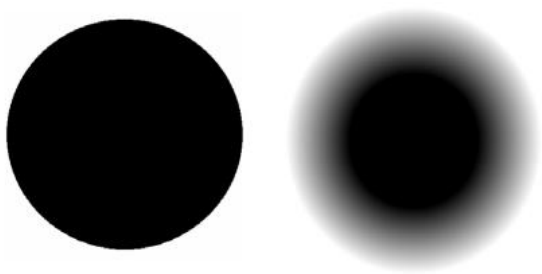


Figure 2.1 : Graphical representation of conventional set and fuzzy set.

2.2.1 Introductory Example

In order to understand the basic principle of fuzzy logic, we present a simple example concerning the regulation of the speed of a car [12]. First, the speed of the car can be estimated either: low, medium, or high. If we rely with classical logic to regulate the speed of the vehicle to an average desired speed, we end up with a simple algorithm as shown in Figure 2.2:

- If the vehicle speed is low: Accelerate;
- If the vehicle speed is average: Do nothing;
- If the vehicle speed is high: Decelerate.

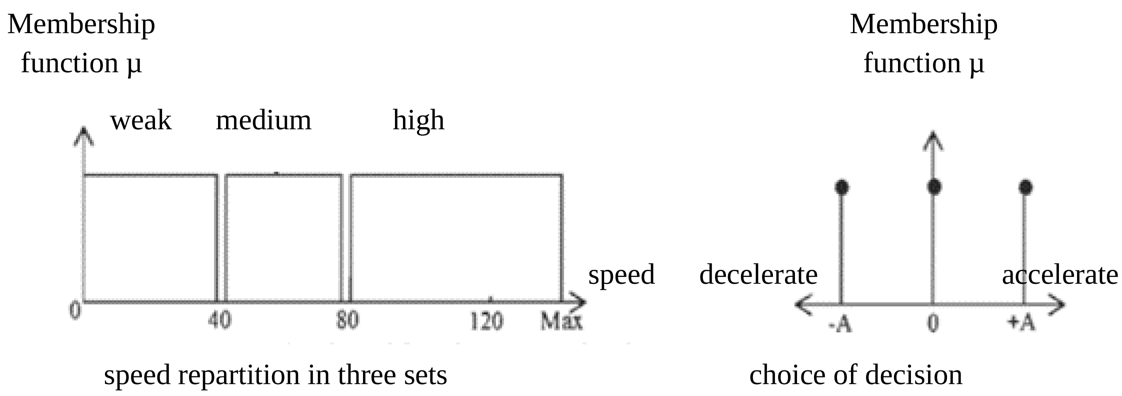


Figure 2.2 : Example of speed regulation with classic logic

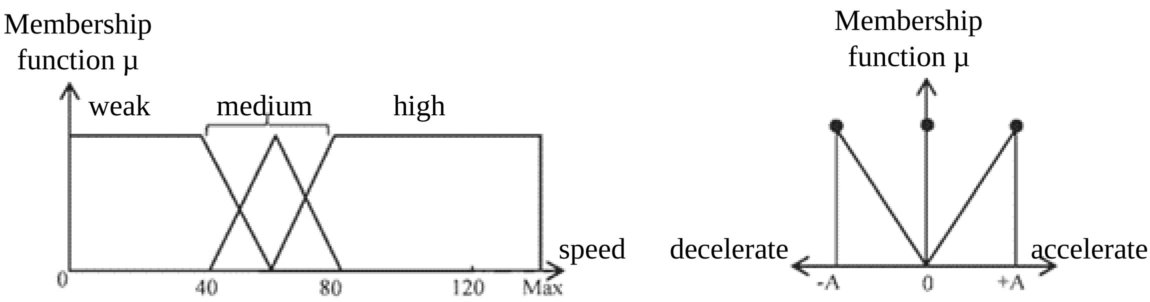
This reasoning is far from to be similar to human reasoning, which is capable of being more precise at the classification level. A speed of 35 km/h according to Boolean logic belongs to the low speed interval, while human sees that it could belong as much to the medium speed interval as to the low speed interval. This is where the principle of fuzzy logic was inspired; the degree of belonging can vary between 0 and 1 in a way that the sum of all gives 1. The speed of the vehicle is not always either clearly low, medium or high, it can be for example 80% low, 20% medium and 0% high, and in this case the decision will not be the same as with classical logic, because fuzzy logic takes into account consideration the passage of interval [12].

In the example considered (Fig. 2.2):

- For a speed lower than 40Km / h, the speed is low;

- For a speed lower than 60Km / h and higher than 40Km / h, we hesitate between low and medium;
- For a speed lower than 80Km / h and higher than 60Km / h, one hesitates between medium and high;
- For a speed greater than 80Km / h, the speed is high.

Now that we have a precise classification of the speed of the car, it will help the controller to deduce a more precise correction which takes into account the passage between the different intervals. For example, when changing from the 'Low' to the 'Medium' interval, the acceleration is no longer constant. The acceleration is an image of the membership function as shown in figure 2.3.



speed repartition in three sets

choice of decision

Figure 2.3 : Example of speed regulation with fuzzy logic.

2.3 Definitions

2.3.1 Universe of discourse

The universe of discourse is the range of variation of the measured or command quantity. In our introductory example: the universe of discourse of the speed is **[0,Max[**. It is imposed by the characteristics of the process (the car). The universe of discourse of acceleration is the set of three values, **-A**, **0** and **+A**. The discourse universe of the response is set according to the dynamics to be obtained.

2.3.2 Linguistic Variables

The universe of discourse is divided into several subsets. Once the value is assigned to the subset to which it belongs, it is represented by the **symbol** or by the **word** that represents that subset. This **symbol** is the linguistic variable. In our example: **Low**, **Medium** and **High** are the **linguistic variables** of the example.

2.3.3 Membership function

The membership function is a representation graph of the amplitude of participation of each entry. In other word, The membership function $\mu(\cdot)$ is the set of degrees of belonging to each linguistic value. There are many types of membership functions. Among them, the two most commonly used in practice are the triangular and trapezoidal functions [13]. Some typical membership functions forms are shown in the figure 2.4.

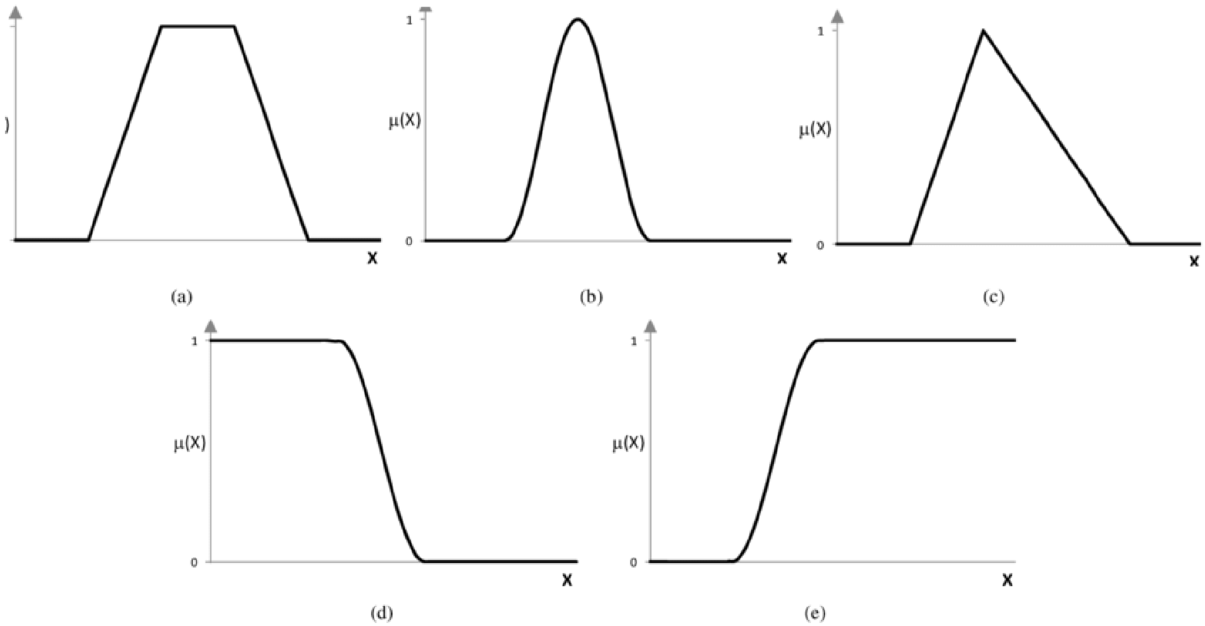


Figure 2.4 : Typical fuzzy set membership function shapes: (a) or trapezoidal, (b) Bell or Gaussian, (c) triangular, (d) Z-shape and (e) S-shape

2.4 The fuzzy operators

In some cases, the response of fuzzy logic depends on more than one condition (two or more). In classical logic, there are operations which manage the overlap of several conditions. The same operators used for the Boolean logic can still be used for the fuzzy logic. In order to easily manipulate fuzzy sets, the operators of the classical set theory are redefined to fit the specific membership functions of fuzzy logic for values strictly between 0 and 1.

2.4.1 The complement (NOT),

The complement in fuzzy logic expression is :

$$NOT(\mu_A(x)) = 1 - \mu_A(x) \qquad \text{Equa 2.1}$$

2.4.2 AND operator

In fuzzy logic, the **AND** operator corresponds to the minimum operation. Applying this operation to two membership functions $\mu_A(x)$ and $\mu_B(x)$, gives the function µc(x) which represents the intersection between the two membership functions.

$$\mu_C(x) = min\ [\mu_A(x), \mu_B(x)] \qquad \text{Equa 2.2}$$

2.4.3 OR operator

The OR operator or the union of two sets corresponds to the maximum operation. The **OR** operation between two membership functions $\mu_A(x)$ and $\mu_B(x)$, gives the function µc(x) which represents the union between the two sets.

$$\mu_C(x) = max\ [\mu_A(x), \mu_B(x)] \qquad \text{Equa 2.3}$$

2.5 Fuzzification

The Fuzzification is the first step in the Fuzzy Logic Controller (FLC) which transforms the inputs Numeric $x_i$into a set of membership values in the interval [0,1] to corresponding fuzzy sets $\mu \quad (x)$.

To understand the reasoning in fuzzy logic, let take another example with the objective is to decide the amount of a tip at the end of a meal in a restaurant, depending on the quality of service and the quality of the food. In this example, we can define membership functions for each fuzzy set [11]:

- Input 1: quality of service. Subsets: poor, good and excellent.
- Input 2: quality of food. Subsets: awful and delicious.
- Output: tip amount. Subsets: low, medium and high.

The figure 2.5 represent the membership functions of the example.

The fuzzy reasoning is based on **fuzzy rules** that are expressed in natural language using linguistic variables. The number of functions membership to be defined for each linguistic variable is defined using expertise human. A fuzzy rule has the form:

If x ∈ A and y ∈ B then z ∈ C, with A, B and C are fuzzy sets.

’If (**the quality of the food** is **delicious**), then (**tip** is **high**)’.

The variable '**Tip'** belongs to the fuzzy set '**high'** to a degree that depends on the degree of validity of the premise, i.e. the membership degree of the variable **'food quality'** to the fuzzy set 'delicious '. The underlying idea is that the more propositions in premise are checked, the more the suggested output actions must be applied. To determine the degree of truth of the proposition fuzzy **'Tip will be High'**, we must define the fuzzy implication. Like other fuzzy operators, there is no single definition of the fuzzy implication: the fuzzy system designer must choose among the wide choice of fuzzy implications already defined, or set it by hand [11].

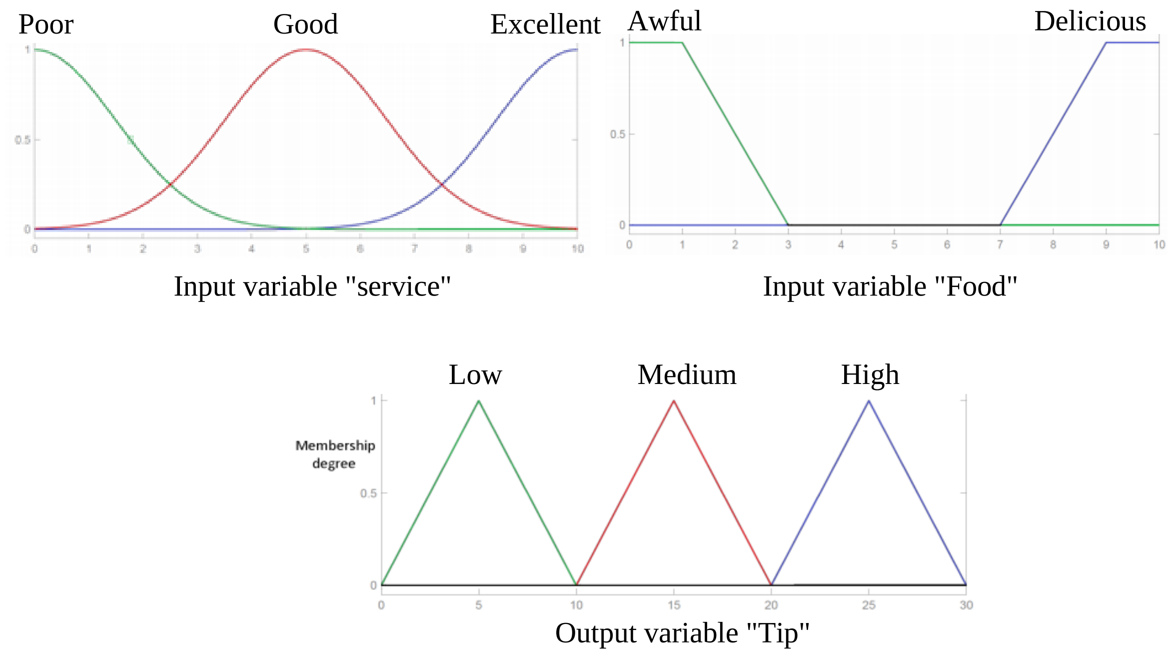


Figure 2.5 : Input and output variables membership functions.

The two most commonly used fuzzy implication are :

Table 2.1 fuzzy implication methods.

Name	Truth value
Mamdani	$min\ [\mu_A(x), \mu_B(x)]$
Larsen	$\mu_A(x) \times \mu_B(x)$

If we choose the **Mamdani** implication, here is what we get for the fuzzy rule **'If (the food quality is delicious), then (tip is high)'** where the **food quality** is rated 8.3 out of 10. The figure 2.6 shows an example of fuzzy implication.

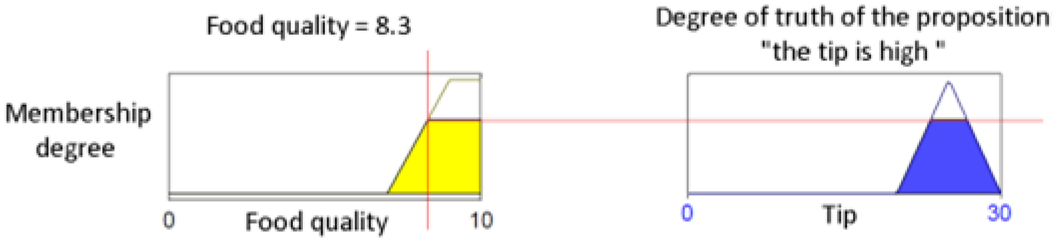


Figure 2.6 Example of fuzzy implication.

The result of the application of a fuzzy rule thus depends on three factors:

1. The definition of fuzzy implication chosen,
2. The definition of the membership function of the fuzzy set of the proposition located at the conclusion of the fuzzy rule,
3. The degree of validity of propositions located premise.

The premise of a fuzzy rule may well be formed from a combination of fuzzy propositions using the fuzzy operators **AND**, **OR** and **NOT**. All the rules of a fuzzy system is called the decision matrix. For the considered example the decision matrix is :

Table 2.2 : Decision matrix

If the service is bad or the food is awful	then the tip is low
If the service is good	then the tip is average
If the service is excellent or the food is delicious	then the tip is high

The figure 2.7 shows what we get for fuzzy rule :

'If (the service is excellent and the food is delicious), then (tip is high)'

where the **quality of service** is rated 7.83 out of 10 and the **quality of food** 7.32 out of 10 if we choose the **Mamdani** implication and the translation of **OR** by **MAX**.

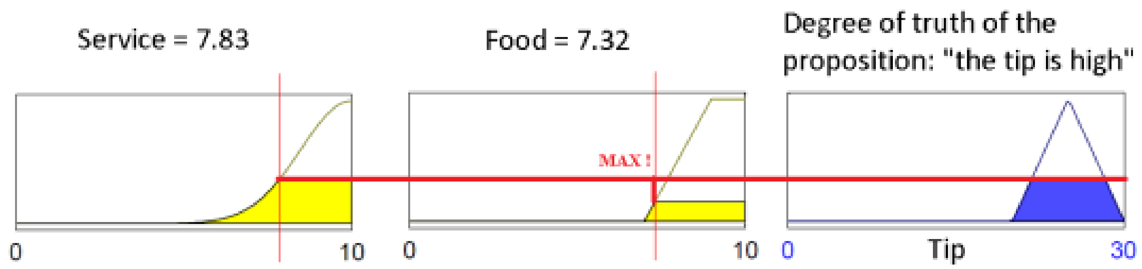


Figure 2.7: Example of fuzzy implication with conjunction OR translated into a MAX

Applying the three rules of the decision matrix, we will obtain three fuzzy sets for the variable **Tip**. The figure 2.8 shows the aggregation of the three fuzzy sets using by the operator MAX which is the almost always used. OK

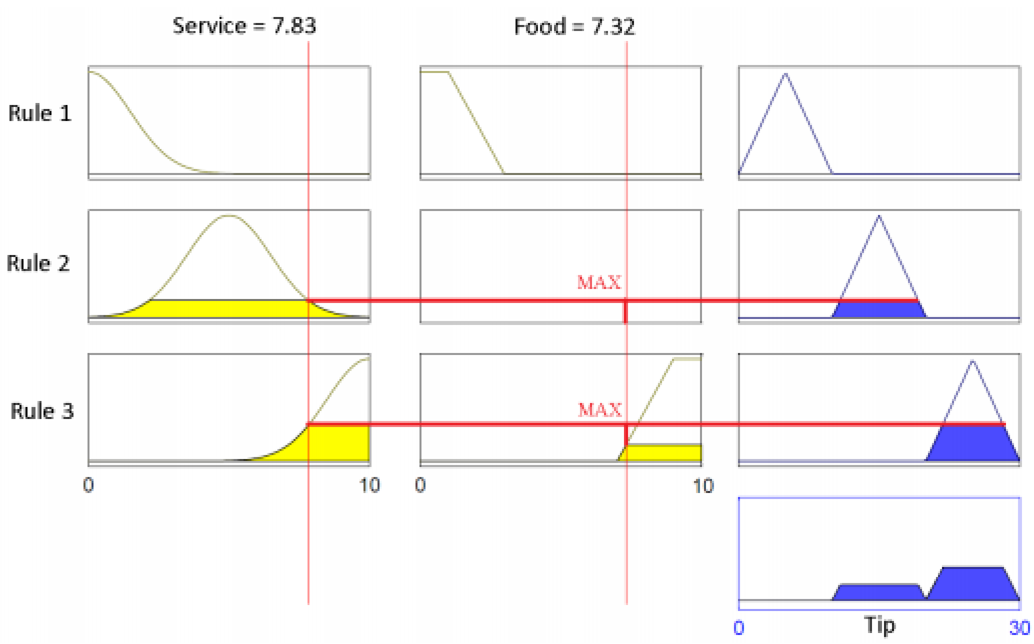


Figure 2.8: Example of fuzzy implication using the decision matrix

Now, we has to make the final decision, namely decide how much the **Tip** will be knowing that the **quality of service** is rated 7.83 out of 10 and **quality of food** 7.32 out of 10. This final step, which allows to switch from the fuzzy set resulting from the aggregation of results to a single decision, is called the defuzzification.

2.6 Defuzzification

The Defuzzification is the last step in fuzzy logic. It consists in converting the fuzzy values into real variables which can be used. Depending on the shape of the desired output, the type of control, the type of the membership functions of the output, there are three basic methods of defuzzification.

1. **The mean of maxima (MeOM)** : sets the output as the average of the abscissas of the maxima of the fuzzy set resulting from the aggregation of the implication results. The figure 2.9.a gives the output using MeOM method.

   The center of gravity (COG). The COG defuzzification is more commonly used. It defines the output as corresponding to the abscissa of the center of gravity of the surface of the membership function characterizing the fuzzy set resulting from the aggregation of the implication results. This method avoids the discontinuities could appear in the MeOM defuzzification, but is more complex and has a greater computational cost. The figure 2.9.b gives the output using COG method.
2. The centre of maxima (COM) : This method is known for its simplicity since it takes into consideration that the vertex of the active space under the membership function. This method is known for its simplicity since it takes into consideration that the vertex of the active space under the membership function.

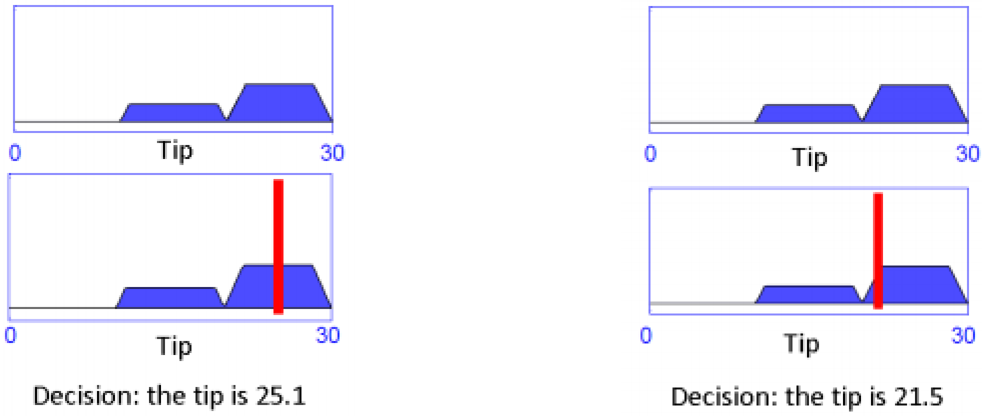


Figure 2.9 : Defuzzification with the methods : a) the mean of maxima (MeOM) and b) center of gravity (COG).

2.7 Fuzzy logic in control

A typical fuzzy logic controller is shown in Figure 2.10. Based on fuzzy logic, the core of the controller is found in its knowledge base, consisting of fuzzy rules that describe the reaction of the regulator, and an inference system that combines the active rules according to the inputs presented to the controller [14].

As the rules and the inference system act on fuzzy subsets, it is necessary to convert the data necessary for regulation from the outside world into linguistic values which can be manipulated by the functions of the knowledge base of logic. fuzzy. The decisions made by the knowledge base are generally linguistic values which must be converted into numerical values in order to apply them to the process to be controlled. [11][12]

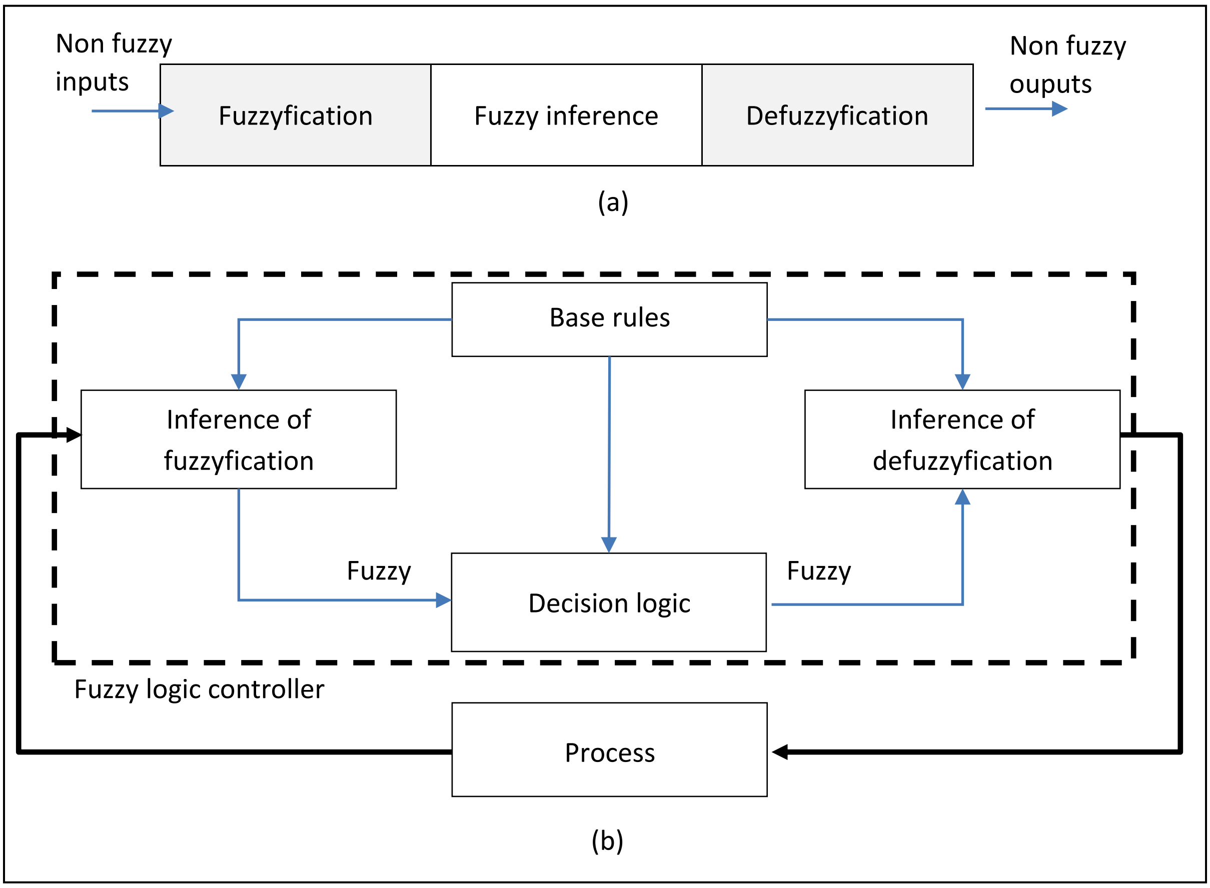


Figure 2.10 : Fuzzy logic controller : a) synoptic scheme b) principal parts

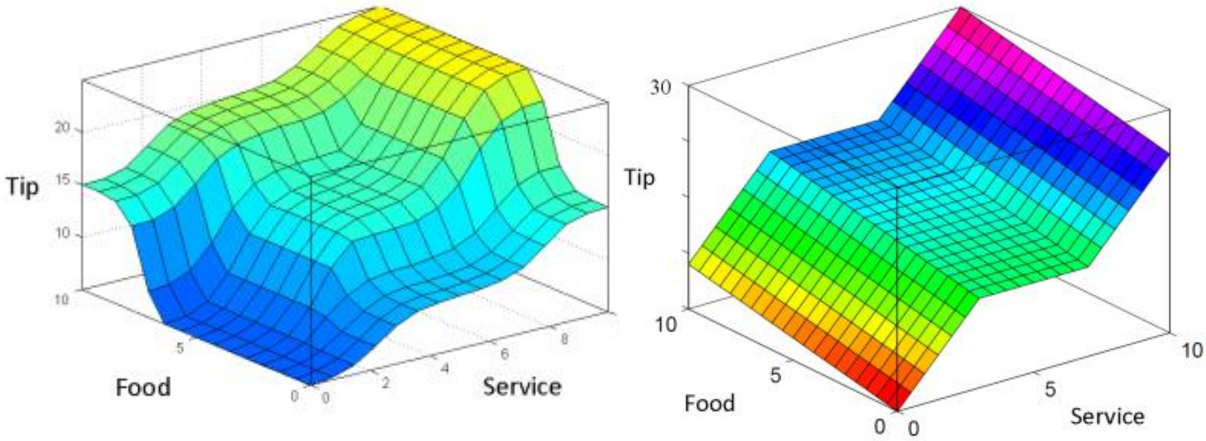
The designer of a fuzzy system must make a number of important choices. These choices are based mainly on the advice of the expert or statistical analysis of past data, in particular to define the membership functions and the decision matrix.

For previous example, we have:

- the input is **'the quality of service is rated 7.83 out of 10 and quality of food 7.32 10'**,
- the fuzzifier corresponds to the 3 linguistic variables **'service quality'**, **'food quality'** and **'tip amount'**,

- • the inference engine is made of the choice of fuzzy operators,
- the fuzzy knowledge base is the set of fuzzy rules,
- the defuzzifier is the part where has to be chosen the method of defuzzification,
- the output is the final decision: **’the tip amount is 25.1’**.

It is interesting to see all the decisions based on each variable with our fuzzy inference system (Figure 2.11.a) compared to the decisions that we would get using classical logic: (Figure 2.11.b)



(a) (b)

Figure 2.11: Decisions of a system based on : a) fuzzy system and b) classical logic

The fuzzy logic allows to build inference systems in which decisions are without discontinuities, flexible and nonlinear, i.e. closer to human behavior than classical logic is. In addition, the rules of the decision matrix are expressed in natural language. This has many advantages, such as include knowledge of a non-expert computer system at the heart of decision-making model or finer aspects of natural language[11].

The construction of the inference table is based on a qualitative analysis of the process. The justification is made in the phase plan of the trajectory that we want to give to the system. The figure shows the response of a system to be controlled where the input variables are the error **e** and its derivative **Δe** while the output variable is variation of the command **Δu**. [15]

For a division into seven subsets (NG,NM,NS,ZE,PS,SP,PMPG) for the input and output variables, we can have an inference table like the one represented by the table in the figure.

Note: The subsets (NG,NM,NS,ZE,PS,PM,PG) are :

NG: Negative Grand   NM: Negative Medium   NS: Negative Small   ZE: Zero

PG: Positive Grand   PM: Positive Medium   PS: Positive Small

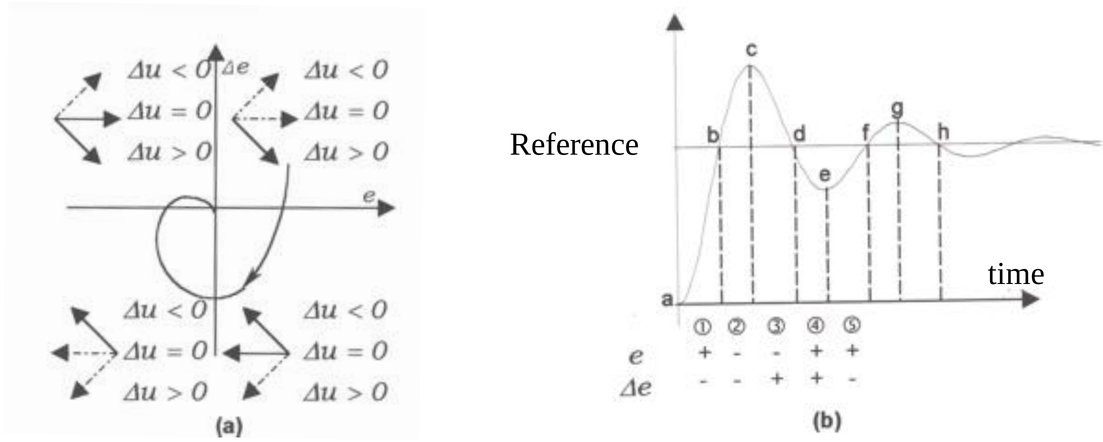


Figure 2.12: Temporal response of a system : a) phase plan and b) temporal plan.

Table 2.3 : Inference table.

Δu		**Δe**						
		NG	**NM**	**NS**	**ZE**	**PS**	**PM**	**PG**
e	**NG**	NG	NG	NG	NG	NM	NS	ZE
	NM	NG	NG	NG	NM	NS	ZE	PS
	NS	NG	NG	NM	NS	ZE	PS	PM
	ZE	NG	NM	NS	ZE	PS	PM	PG
	PS	NM	NS	ZE	PS	PM	PG	PG
	PM	NS	ZE	PS	PM	PG	PG	PG
	PG	ZE	PS	PM	PG	PG	PG	PG

2.8 Conclusion

In this chapter, we have presented the various notions of fuzzy logic. We have given the different blocks of a fuzzy regulator. The difficulty of the design lies in the configuration of each block as it depends on human expertise. In the next chapter, we will introduce the Control of a magnetic suspension system.

3 Chapter 3

Control of a magnetic suspension system

3.1 Introduction

Magnetic suspension is a technology with which the object is suspended by electromagnetic force. It is used in several fields for example a magnetic train system (in Shanghai, China). The magnetic suspension constitutes an unstable open-loop system, in fact everyone knows that an object facing an electromagnet is either completely attracted or falls irreparably and that it is not natural to keep the object without contact [16].

The magnetic levitation systems are appealing. it can be achieved by implementing different control algorithms without any hardware modification to the mechanical parts of the whole system .

Fuzzy logic controller (FLC) is alternative to existing classical or modern controllers for designing the nonlinear control systems. It does not require system models or complex mathematical equations and it describe the relationship between inputs and outputs [2].

3.2 Modelization

3.3 Simple magnetic suspension system

The magnetic suspension system consists of an electromagnet, a coil and a distance sensor. Figure 3.1 shows the basic principle where URL and i are the voltages and the current of the electromagnet with resistance R and inductance L, c is an unknown parameter, m is the mass of the coil and l is the distance between the electromagnet and the coil [17].

From the second Newton law we can write

$$mg - Fm = m\frac{d^2l}{dt^2} \qquad \textbf{Equa 3.8}$$

The magnetic force depends on the current i, the distance l, and the parameter c

$$Fm = c\frac{i^2}{l^2} \qquad \textbf{Equa 3.9}$$

The electric dynamic of the system is modeled by the following equation:

$$u_{RL}(t) = L\frac{di}{dt} + ri \qquad \textbf{Equa 3.}10$$

The sensor and the actuator can be modeled with static functions where equation (4) is the model of the sensor and equation (5) is the model of the actuator

$$y = K_{sens}\, l + U_{sens}, \quad K_{sens} = -4\left[\frac{V}{mm}\right], \quad U_{sens} = 10[V]$$ **Equa 3.4**

$$u = K_{act}u_{RL} + U_{act}, \quad K_{act} = 2\,, \qquad U_{act} = -10[V]$$ **Equa 3.5**

By using equations (1)-(3), the nonlinear unstable differential equation is obtained:

$$\frac{Lm}{c}\left(g - \frac{d^2l}{dt^2}\right)\frac{dl}{dt} - \frac{Lm}{2c}\, l\, \frac{d^3l}{dt^3} + \frac{Rm}{c}\, l\left(g - \frac{d^2l}{dt^2}\right) - u_{RL}\sqrt{\frac{m}{c}\left(g - \frac{d^2l}{dt^2}\right)} = 0$$ **Equa 3.6**

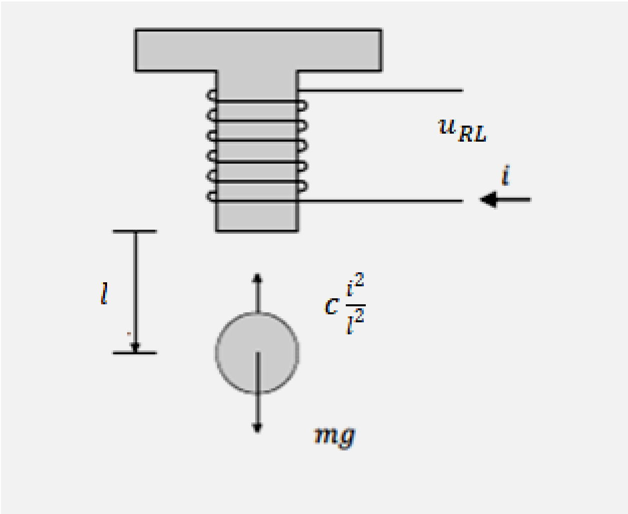


Figure 3.11 : Magnetic Levitation System

3.3.1 The didastel magnetic suspension

This Magnetic levitation system consists of an electromagnet, a metal sphere and an infra-red sphere position sensor. The magnetic ball suspension system can be categorized into two systems: a mechanical system and an electrical system. The sphere position in the mechanical system can be controlled by adjusting the current through the electromagnet where the current through the electromagnet in the electrical system can be controlled by applying controlled voltage across the electromagnet terminals [2].

Figure 3.12 :Didastel magnetic suspension (Maglev unit)

3.3.2 Electrical part

To simplify the system, we will model this part by an inductor L in series with a resistance. Then we can obtain the time equation of the electrical part:

$$K1 \cdot U = RI + L\frac{dI}{dt} \qquad \textbf{Equa 3.7}$$

Using the Laplace transform, we get:

$$G1 = \frac{I(p)}{U(p)} = \frac{K1}{1+\tau_e p} \qquad \textbf{Equa 3.8}$$

With K1≈ 0.24 A / V andτ_e = L / R ≈ 1ms

3.3.3 Mechanical part

The magnetic force (F) is generated by the current (I) which travels through the coil and also depends on the position (X).

$$m\frac{d^2X}{dt^2} = mg - F(X,I) \qquad \textbf{Equa 3.9}$$

$$F(X,I) = a\,I(t) + bX(t) \qquad \textbf{Equa 3.10}$$

The mass of the balloon is low, the gravity (mg) is therefore negligible compared to the acceleration.

$$a\,I(t) + bX(t) = -m\frac{d^2X}{dt^2} \textbf{Equa 3.11}$$

By setting τ_m^2= m / b and K2 = -a / bwe get

$$\boldsymbol{G2} = \frac{\boldsymbol{X(p)}}{\boldsymbol{I(p)}} = \frac{\boldsymbol{K2}}{\boldsymbol{1 - \tau_m^2 . p^2}} \textbf{Equa 3.12}$$

With K2 ≈ -25.8 andτ_m ≈ 0.05 ms .

3.3.4 Position sensor

The position of the balloon varies between -40mm and 0mm. And the signal obtained varies between -10V and 0V. The transfer function is written:

$$G3 = \frac{U(p)}{X(p)} = k3 \textbf{Equa 3.13}$$

With K3 =0.25 V/mm

3.3.5 Global transfer function

$$G = G1 \cdot G2 \cdot G3 = \frac{-K}{(1+\tau_e\, p)\cdot(1+\tau_m^2 p^2)} \textbf{Equa 3.14}$$

Where $K \approx 1.55 \quad \tau_e \approx 1ms \quad \tau_m \approx 0.05ms$

3.4 CONTROLLER

In this section, control schemes like PID and Fuzzy logic controller are proposed.

3.4.1 PID Control

The PID controller as shown schematically in Figure3.3, is well known and widely used to improve the dynamic response as well as to reduce or eliminate the steady state error. The derivative controller adds a finite zero to the open loop plant transfer function and improves the transient response. The integral controller adds a pole at the origin, thus increasing system type by one and reducing the steady state error due to a step function to zero [2].

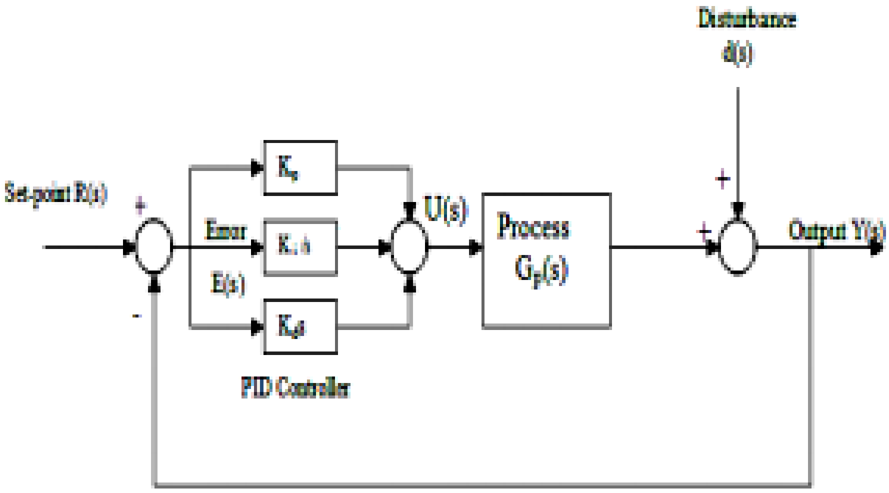


Figure 3.13 : Schematic of conventional PID Controller

$$U(s) = \left(K_p + \frac{K_i}{s} + pK_d\right) E(s) \quad \textbf{Equa 3.15}$$

3.4.2 Fuzzy Logic Controller

The fuzzy logic system is processed as: Firstly, crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This set is known as fuzzification. Afterwards, an inference is made based on a set of rules. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification step. The evaluations of the fuzzy rules and the combination of the results of the individual rules are performed using fuzzy set operations. The operations on fuzzy sets are different than the operations on non-fuzzy sets. Let μA and μB are the membership functions for fuzzy sets A and B. The mostlyused operations for OR and AND operators are max and min, respectively [2].

Fuzzy rules are expressed in the form of fuzzy conditional statements Ri of the type

Ri : if x is small THEN y is large

Where x and y are fuzzy variables, and small and large are labels of fuzzy set. If there are i =1 to n rules, the rule set is represented by union of these rules

R=R1 else R2 else …Rn

A fuzzy logic controller is based on a collection of R control rules. The execution of these rules is governed by the compositional rule of inference.

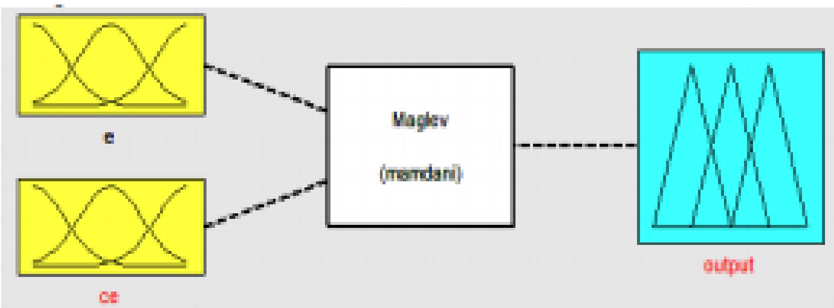


Figure 3.14 :general architecture of a Fuzzy logic system

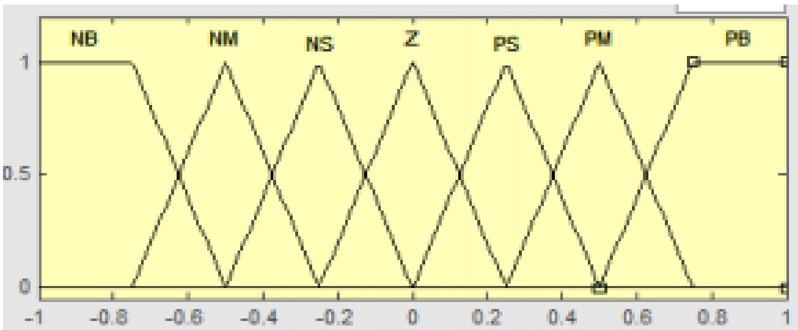


Figure 3.15 : Input e and ce Membership Function

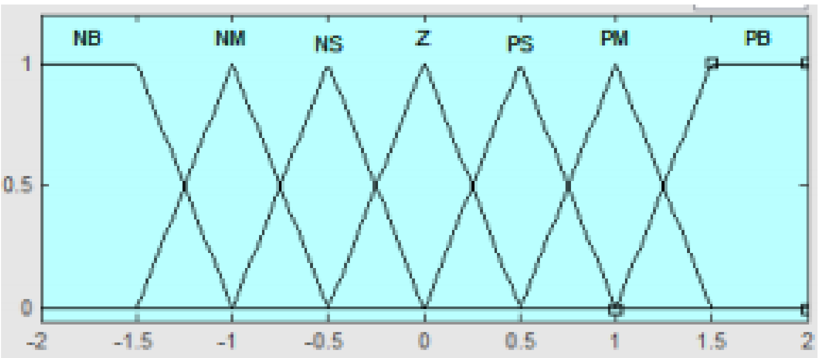


Figure 3.16 : Output Membership Function

Tableau 3.1 : Fuzzy Rules Base

ce / e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM

Tableau 3.2 : Fuzzy Rules Base

Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

3.5 Discussion

In case of PID controller the integral action in magnetic levitation system can improve the system performance in terms of error minimization. However because of the fact that the system is not self starting the integral action has to be turned on when the ball acquires the stabilized position by the PD controller. Otherwise the huge error of ball position would be integrated by the controller resulting in unrealistic control values. This would cause system destabilization [2].

Position control: P=4,D=0.2 and I=2.

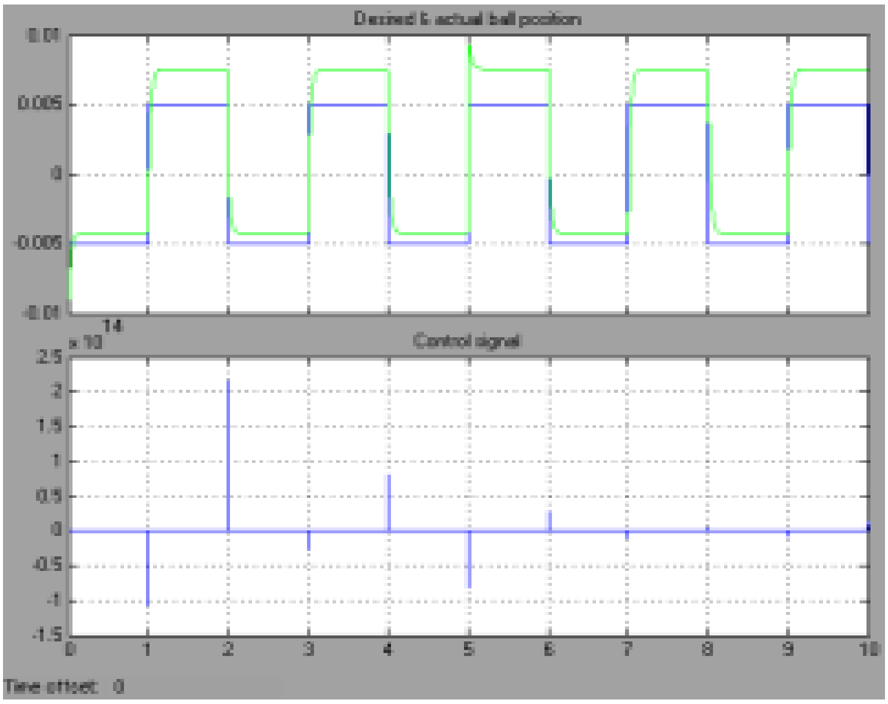


Figure 3.17 : PID ball levitation control

In case of Fuzzy logic control (FLC), the control strategy is based on human experience to construct the rule base for FLC

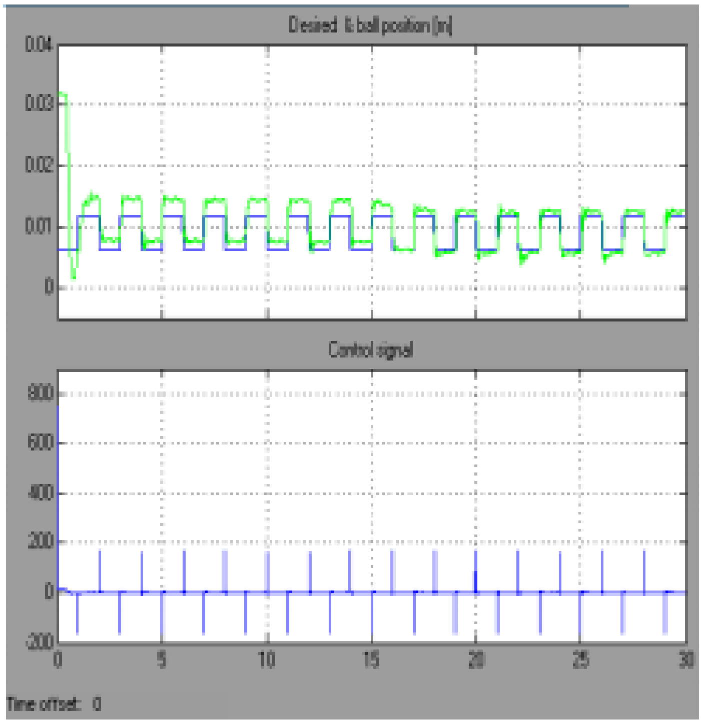


Figure 3.8 : Response of Fuzzy logic controller

Fuzzy logic control has better tracking response as compared with the PID controller.

3.6 Conclusion

In this chapter, we have presented the control strategies like PID and Fuzzy logic controller. These strategies can successfully control the magnetic levitation system. In the next chapter, we will introduce attack the realization of a magnetic suspension system.

4 Chapter 4

Realization of a magnetic suspension system

4.1 Introduction

The main goal of our work to make a magnet piece floating above another magnet piece and not falling down and this process quite complex without any microcontroller. We use the Arduino to control a magnetic suspension system. This system contains permanent magnets, electromagnets, hall sensors, integrated circuits. Has power supply, control circuits then has an Arduino board contains the program which allows us to achieve balanced magnetic suspension

4.2 Principle

The magnetic suspension consist of two parts, the base piece and the levitate piece. The base pieces consist of magnets to create a round magnetic field and electromagnets to control that magnetic field.each magnet have North Pole and South Pole, as know that the same-poles repel. Four cylindrical magnets are placed in a square and have the same polarity, forming a round magnetic field upward to push any magnet, which has a same pole and in between of them. There are four electromagnets, they are placed in a square, two symmetric magnets is a pair.This part is at the bottom.

Levitated piece or Floating piece consists of a magnet levitate above the base piece

The floating piece is raised by the magnetic field of the bottom magnets because they are the same poles. It however tends to turn over to fall down and attract in each other [18].

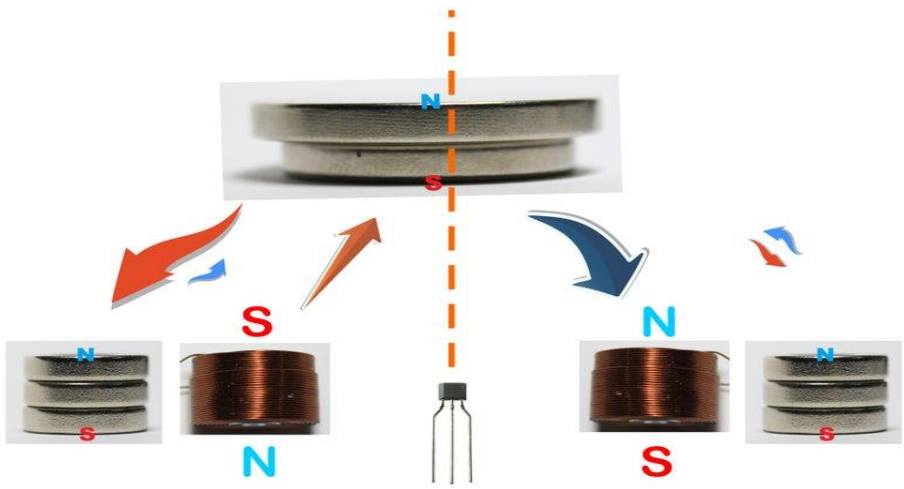


Figure 4.1 : unstable magnetic levitation case

To keep the top magnet floating and balanced, electromagnets will create magnetic fields to push or pull to balance it, dependence on sensors. Electromagnets are controlled in X and Y axes, as a result the levitate piece being kept balanced and floating.

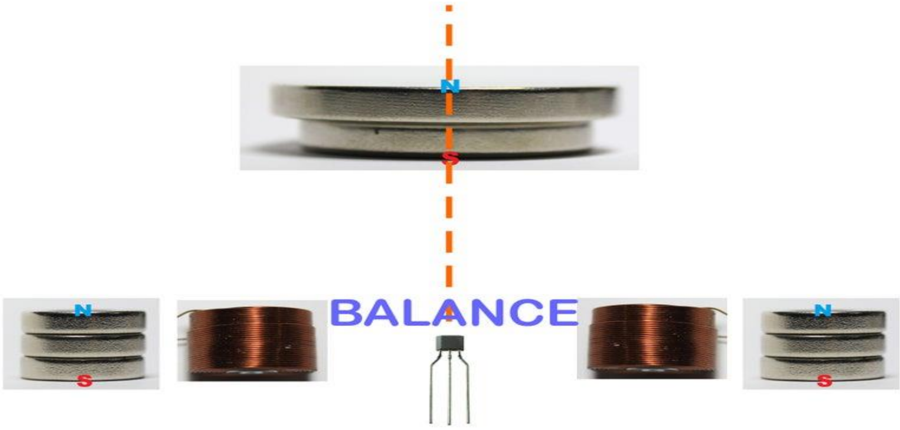


Figure 4.2 : balanced magnetic levitation

Controlling electromagnets is not easy, this requires a servo system as PID controller.

4.3 PID Controller

A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. PID algorithm consists of three basic coefficients; proportional, integral and derivative which are varied to get optimal response. A PID controller calculates an error value as the difference between a measured process variable and a desired set point [19][20].

The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.

4.3.1 Fundamental operation

The distinguishing feature of the PID controller is the ability to use the three control terms of proportional, integral and derivative influence on the controller output to apply accurate and optimal control. The block diagram on figure 4.3 shows the principles of how these terms are generated and applied. It shows a PID controller, which continuously calculates an error value [21].

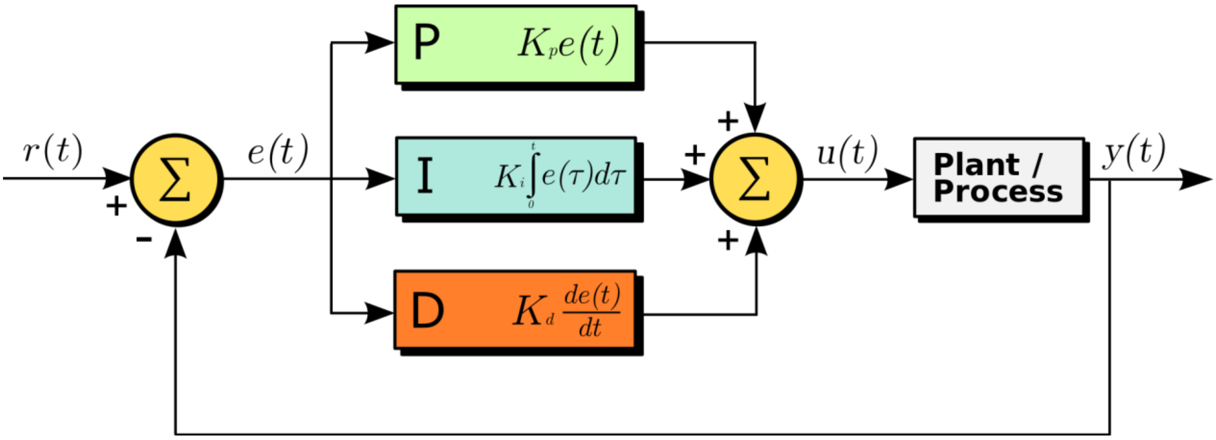


Figure 4.3 : A block diagram of a PID controller

- e(t) as the difference between a desired setpoint and a measured process variable.
- r(t) is the desired process value or set point (P).
- y(t) is the measured process value (PV).
- u(t) is control variable .

- A proportional controller (Kp) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error.
- An integral control (Ki) will have the effect of eliminating the steady-state error, but it may make the transient response worse.
- A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response but little effect on rise time

4.3.2 PID control

The PID adjusts the output trying to make the input equal the setpoint.To achieve stability we need to find appropriate configuration

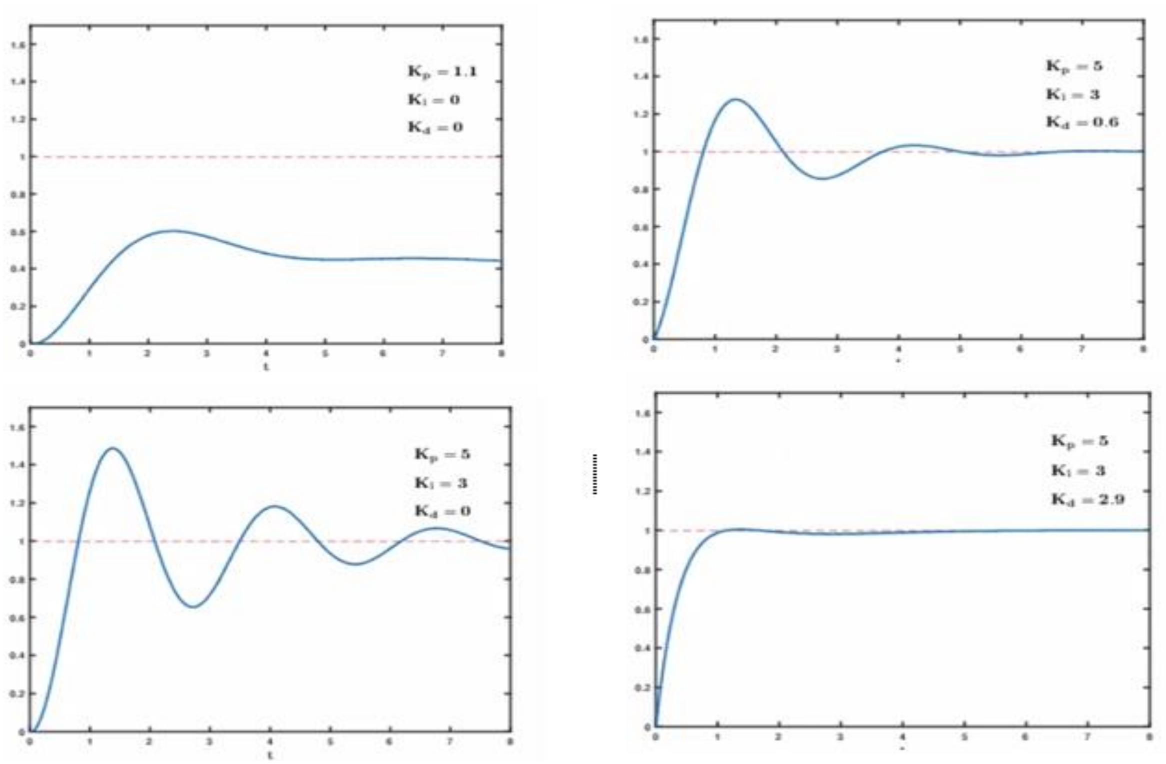


Figure 4.4: system output controlled by PID

4.3.3 Overview of Methods

There are several methods for tuning a PID loop. The most effective methods generally involve the development of some form of process model, then choosing P, I, and D based on the dynamic model parameters [20].

Tableau 4.1: Choosing a Tuning Method

Method	Advantages	Disadvantages
Manual Tuning	No math required , Online	Requires experienced personnel
Ziegler-Nichols	Proven Method, Online	Process upset, some trial-and-error, very aggressive tuning
Cohen-Coon	Good process models	Some math; offline; only good for first-order processes
Software Tools	Consistent tuning; online or offline - can employ computer-automated control system design (CAutoD) techniques;	Some cost or training involved

In this project:

1. The Input is the current realtime value from hall sensor, which are updated continuously because the position of the floating magnet will change in real time.

2. Setpoint is the value from hall sensor, which is measured when the floating magnet is in the balance position, at the center of the magnets base. This index is fixed and doesn't change over time.
3. Output would be the speed to control electromagnets.

4.4 Arduino

The Arduino board is a platform used to carry out more developed electronic projects. It is made up of a programmable physical circuit known as microcontrollers and software used to create and download code from the computer to the card [22].

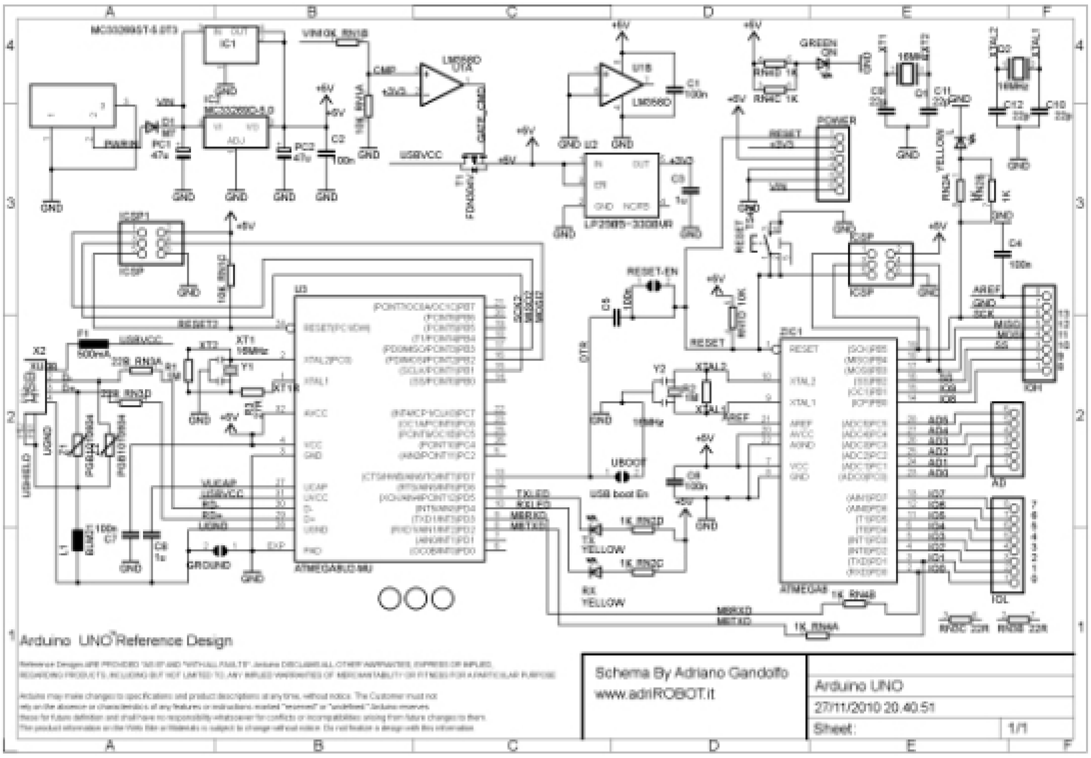


Figure 4.5: Circuit diagram of Arduino Uno

4.4.1 Description of the card

It contains the following elements:

The microcontroller: considered to be the brain of the card. The power supply: It is that of the microcontroller: 5V regulated (USB port) or 7 to 12V from external power supply. Visualization: by millimeter-sized LEDs. They are there to test the equipment with the connection with microcontroller and the other LEDs are for transmission and reception when the programs download into the microcontroller.[] The connectors: The connectors are:

- 0 to 13: Digital input / output;
- A0 to A5: Analog Input / Output;
- GND: ground (0V);
- 5V: the + 5V power supply;
- 3.3V: power supply + 3.3V;

4.4.2 Arduino software:

Description: This software has the following functions:

- Write and compile the program for the card
- Connect and transfer programs
- Communicate with the card

4.4.3 Language:

The program is linked to a series of elementary instructions in text form so the card reads after executes the instructions one after the other.

- A computer
- An arduino card
- Program linked to the Arduino
- Language syntax: C and C ++

4.5 L298N module

For our suspension system, we want to control his 4 direct current electromagnets, so we have to vary their speed. To do this, we chose the double H bridge, the L298.

Dual H-Bridge L298N are typically used in controlling motors speed and direction of two DC motors, or control one bipolar stepper motor with ease. The L298N H-bridge module can be used with motors that have a voltage of between 5 and 35V DC.

In this project I used L298N to control two pair of electromagnet coils and use 5V output to power hall sensor.

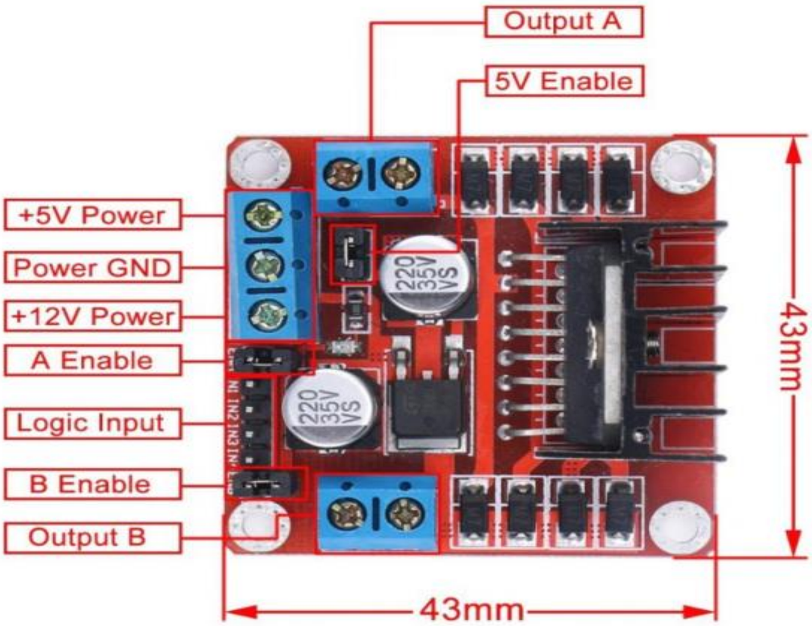


Figure 4.6: Board Dimension and Pins Function

4.6 The SS495a Hall sensor

The SS495a is a Linear Hall Sensor with analog output.Notice the difference between analog output and digital output, we can't use a sensor with digital output in this project, it only has two states of 1 or 0, so you can't measure the output of magnetic fields.

An analog sensor will result in a voltage range of 250mV to Vcc, which you can read with Arduino's Analog Input [18].Two hall sensors are required to measure the magnetic field in both the X and Y axes

4.7 LM324 OpAmp

Operational amplifiers (op-amps) consists of four independent, high gain internally frequency compensated operational amplifiers which are designed specifically to operated from a single power supply over a wide voltage range. Operation from split power supplies is also possible. Application areas include transducer amplifier, DC gain blocks and all the conventional OP amp circuits which now can be easily implemented in single power supply system [23].

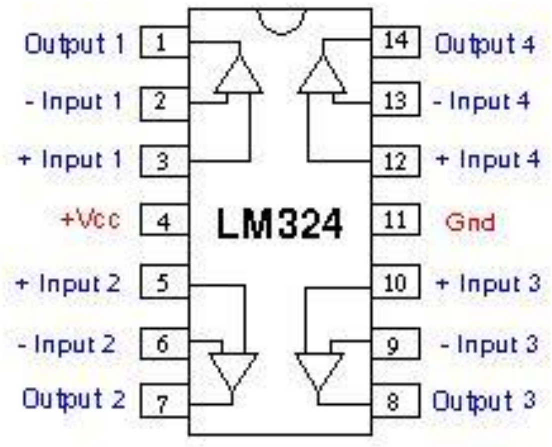
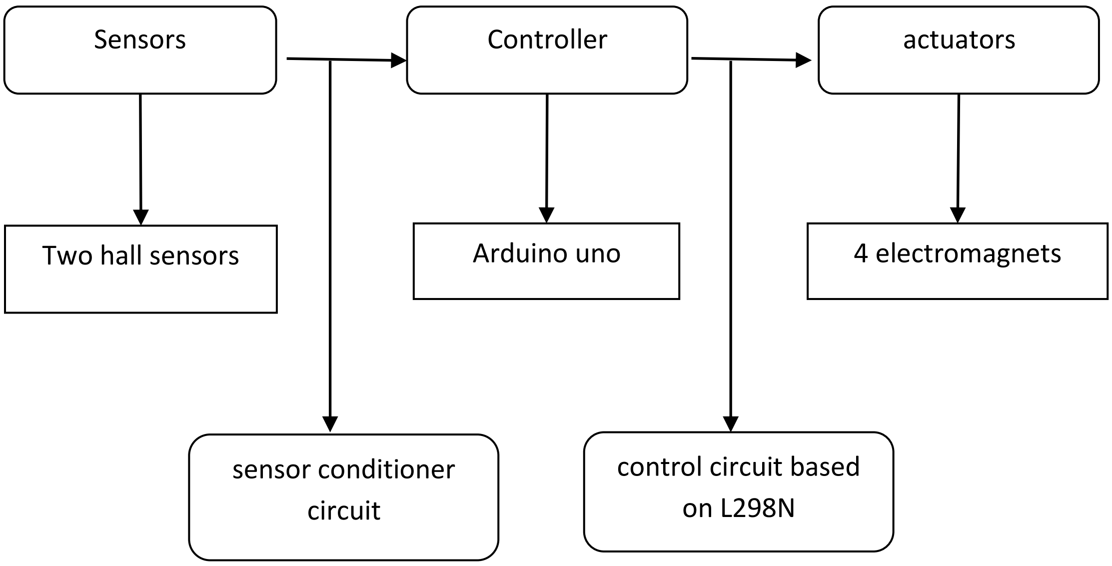


Figure 4.7: LM324 Pins connections

4.8 Realization of the circuits

4.8.1 The design of the magnetic suspension system

The basic structure



4.8.2 The sensors:

First of all and since the main task of the project is magnetic levitation, it needs a hall sensor. We used 2 sensors (ss495a), one to determine the signal of the x axis and the other of the y axis.

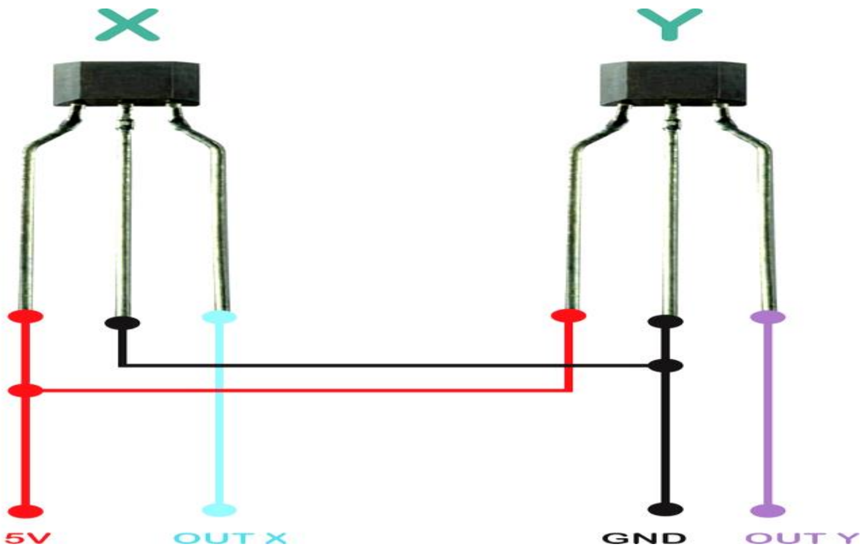


Figure 4.8 : The ss945 hall sensor

Sensor module fixed between the electromagnets, each sensor must be square with two electromagnets, one on the front and the other on the back.

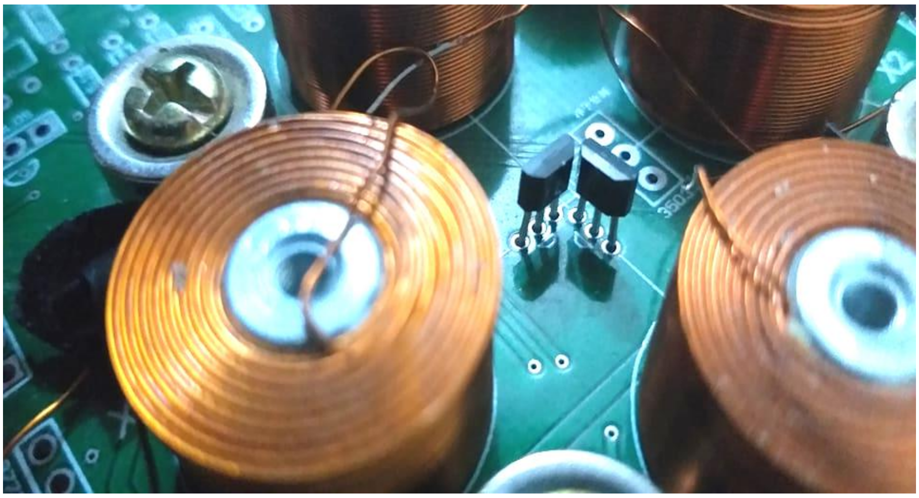


Figure 4.9 : The placement of sensors

4.8.3 OpAmp Circuit

The OPAmp circuit is given at the figure 4.10.

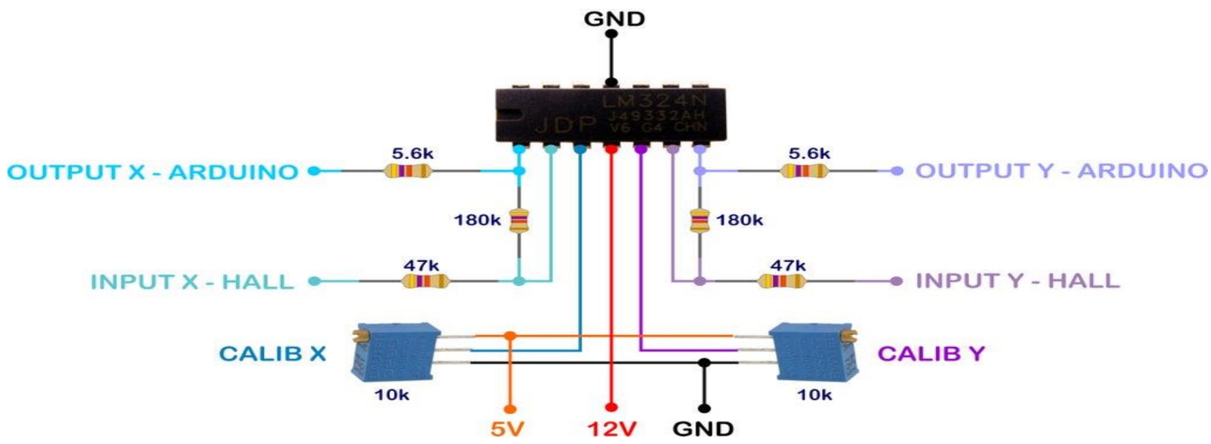


Figure 4.10 :The OPAmp circuit

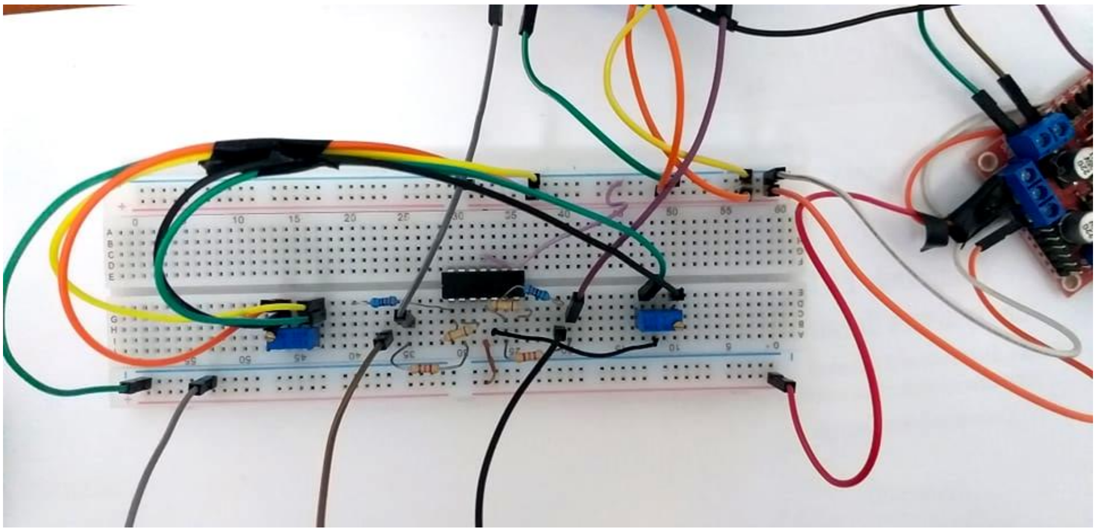


Figure 4.18: The realisation of OPAmp circuit

4.8.4 The Sensor Module and base piece

The Sensor Module is represented in the figure 4.12.

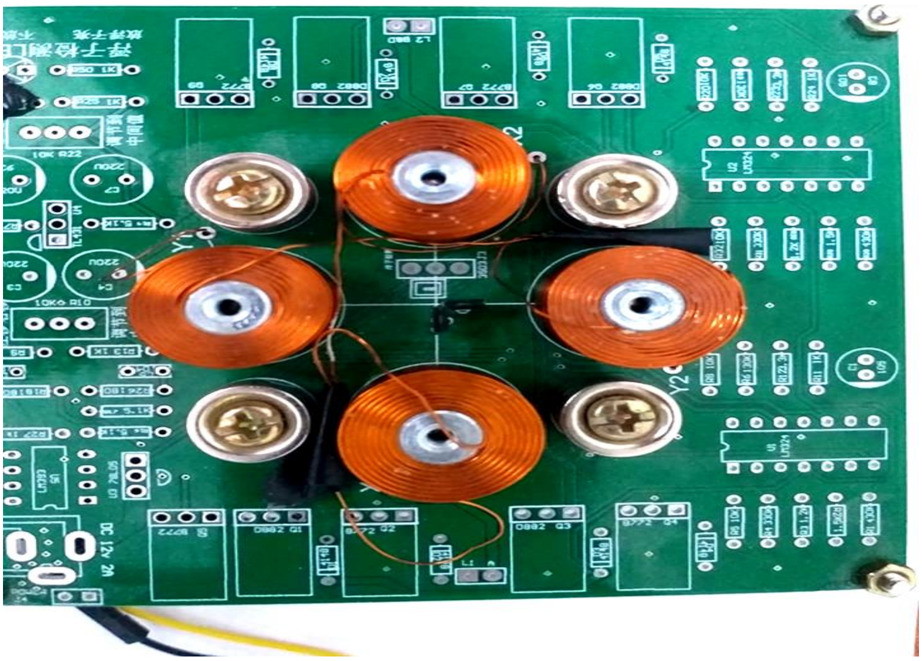


Figure 4.12 : base piece

4.8.5 The circuit L298N

The circuit L298N circuit with Arduino card is shown at the figure 4.13.

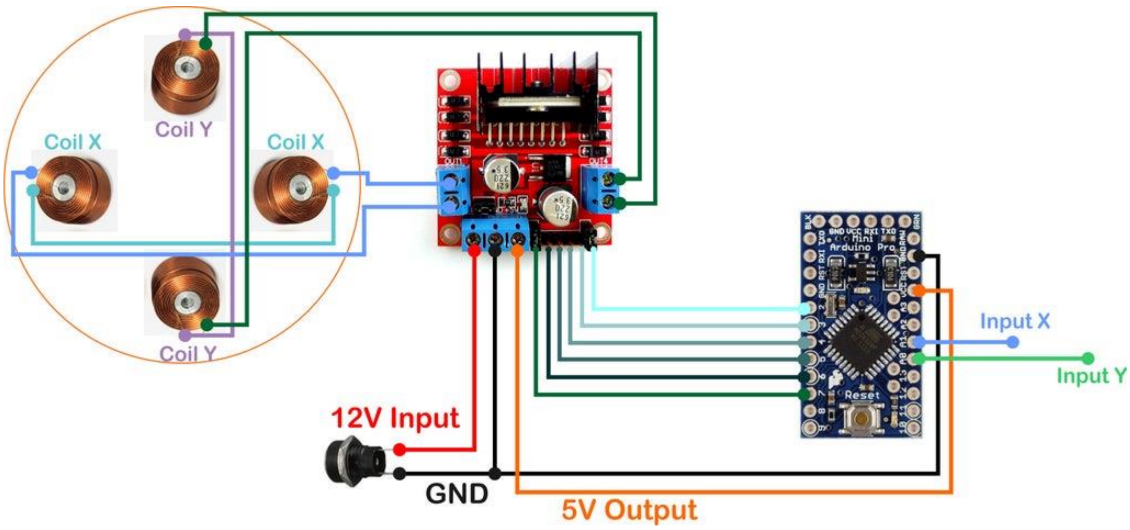


Figure 4.13 : L298N and arduino circuit

Connect the L298N module to the Arduino following to the schematic above.

L298N ===> Arduino . Out 5V ===> VCC. GND ===> GND

EnA ===> 7. In1 ===> 6 In2 ===> 5

In3 ===> 4 In4 ===> 3 EnB ===> 2

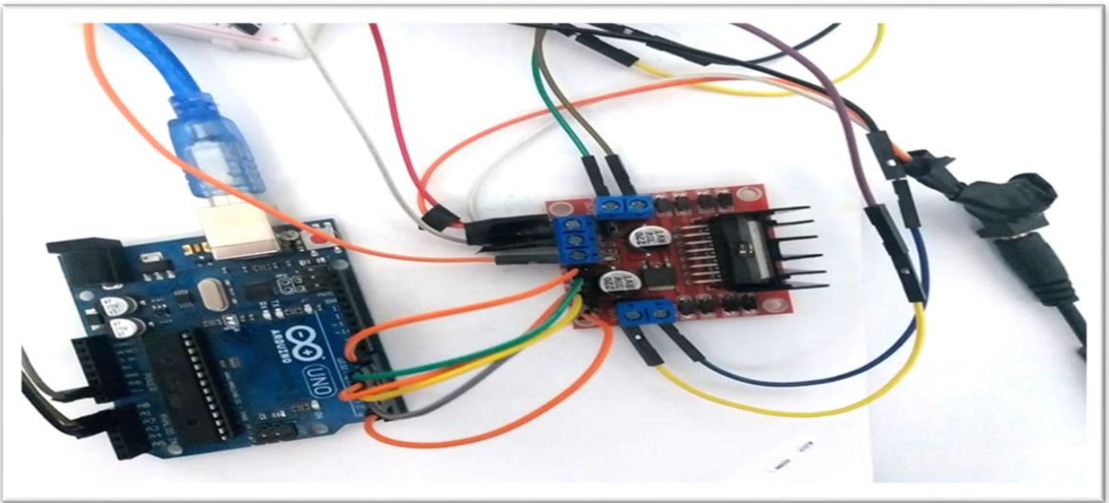


Figure 4.14 : L298N and arduino circuit

After installing the parts, we get a magnetic suspension device (figure 4.15) that remains only to be programmed

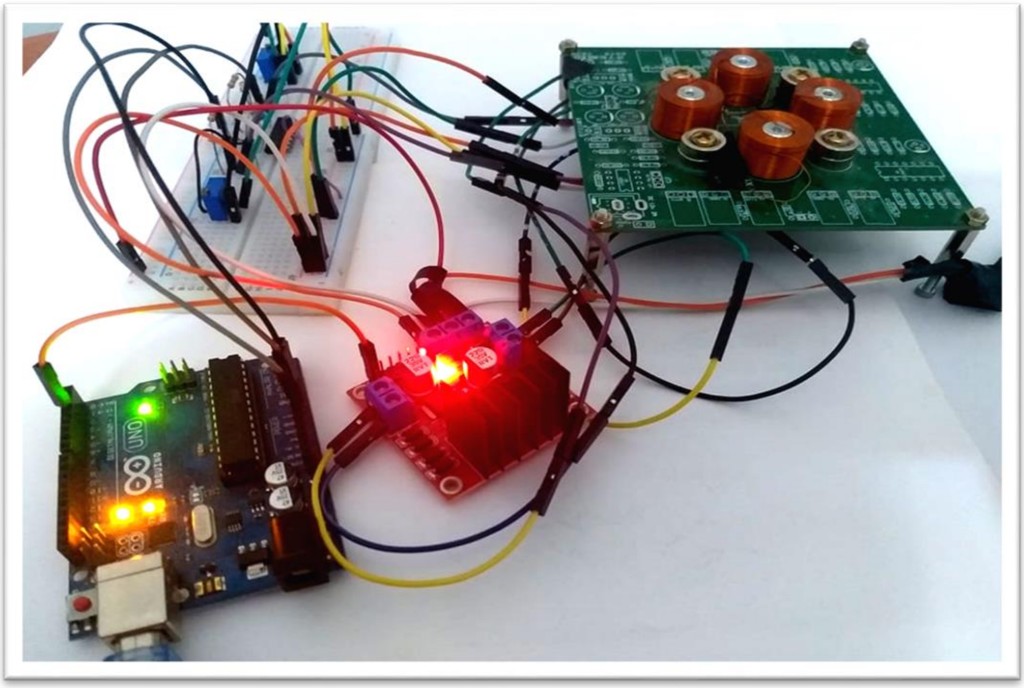


Figure 4.15:magnetic suspension system

4.9 Calibration Setpoint Value

Load program ReadSetpoint.ino (figure 4.16) to Arduino This program will read the values of the hall sensor and send it to the computer via the serial port.

Depend on the values on the screen, make adjustments by adjusting the two potentiometer. The best value is 560, at which point the output of the sensor is about 2.5V.

After setting the setpoint, place the floating magnet piece above the base piece and shake it to see the change of the setpoint on the screen.

```
int Setpoint_X, Setpoint_Y;
void setup() {
  Serial.begin(9600);
  Serial.print("Hello, This is program to get X Y setpoint value!\r\n");
}

void loop() {
  // read the value from the sensor:
  Serial.print("Setpoint_X: ");
  Serial.print(analogRead(A1));
  Serial.print("      ");
  Serial.print("Setpoint_Y: ");
  Serial.print(analogRead(A0));
  Serial.print("\r\n");
  delay(100);
}
```

Figure 4.16 : ReadSetpoint program

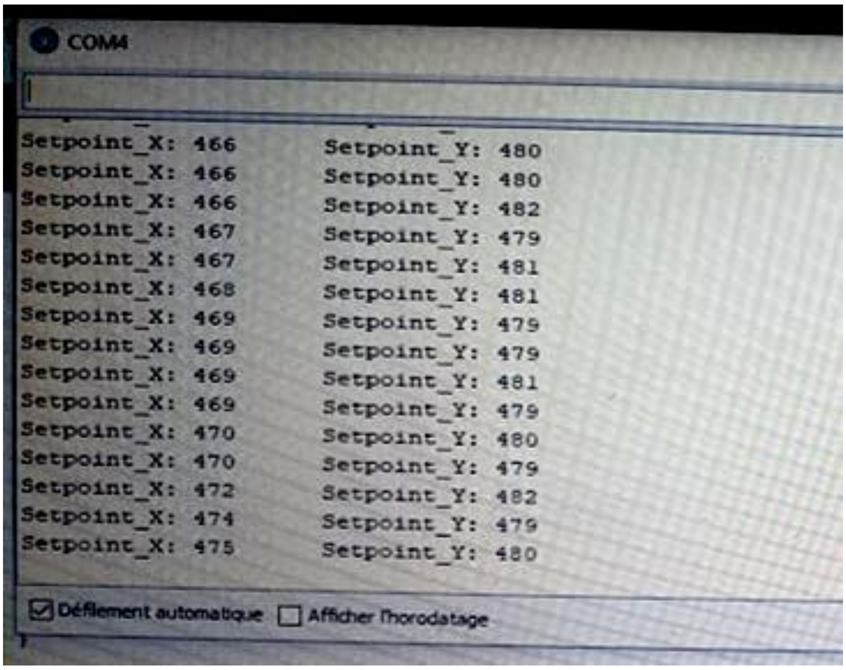


Figure 4.17 : the values of the hall sensor

4.10 Main Program

After calibrate the Setpoint value, Load the Levitation.ino main program (figure 4.18)

```
#include <PID_v1.h>
#define IN1 7
#define IN2 6
#define IN3 5
#define IN4 4
#define ENA 9
#define ENB 3
#define BL 2

double Setpoint_X, Input_X, Output_X,X_plus;
double p_X = 1,i_X = 0,d_X = 0.01;
double Setpoint_Y, Input_Y, Output_Y,Y_plus;
double p_Y = 1,i_Y = 0,d_Y = 0.01;

int i,on_put=1;

unsigned long time;

PID PID_X(&Input_X, &Output_X, &Setpoint_X,p_X,i_X,d_X, DIRECT);
PID PID_Y(&Input_Y, &Output_Y, &Setpoint_Y,p_Y,i_Y,d_Y, DIRECT);

char inByte='9',nullByte,run_flag,run_dirict;
float go_step;
```

```
void turn_X(int a)
{
  if(a>=0)
  {
    digitalWrite(IN1,1);
    digitalWrite(IN2,0);
    analogWrite(ENA,a);
  }
  else
  {
    a=-a;
    digitalWrite(IN1,0);
    digitalWrite(IN2,1);
    analogWrite(ENA,a);
  }
}

void turn_Y(int a)
{
  if(a>=0)
  {
    digitalWrite(IN3,0);
    digitalWrite(IN4,1);
    analogWrite(ENB,a);
  }
```

```
  else
  {
    a=-a;
    digitalWrite(IN3,1);
    digitalWrite(IN4,0);
    analogWrite(ENB,a);
  }
}

void setup()
{
  pinMode(IN1,OUTPUT);
  pinMode(IN2,OUTPUT);
  pinMode(IN3,OUTPUT);
  pinMode(IN4,OUTPUT);
  pinMode(ENA,OUTPUT);
  pinMode(ENB,OUTPUT);
  pinMode(BL,OUTPUT);
  digitalWrite(IN1,0);
  digitalWrite(IN2,0);
  digitalWrite(IN3,0);
  digitalWrite(IN4,0);
  analogWrite(ENA,0);
  analogWrite(ENB,0);
  Setpoint_X = 598;//560;
  Setpoint_Y = 592;//560;
```

```
  PID_X.SetTunings(p_X,i_X,d_X);
  PID_Y.SetTunings(p_Y,i_Y,d_Y);
  PID_X.SetOutputLimits(-255,255);
  PID_Y.SetOutputLimits(-255,255);
  PID_X.SetSampleTime(5);
  PID_Y.SetSampleTime(5);
  PID_X.SetMode(AUTOMATIC);
  PID_Y.SetMode(AUTOMATIC);
  Serial.begin(9600);
}

void loop()
{
  Input_X = analogRead(A1);
  Input_Y = analogRead(A2);

  PID_X.Compute();
  PID_Y.Compute();
  turn_X(Output_X);
  turn_Y(Output_Y);
  Serial.print("output_X: ");
  Serial.print(Output_X);
  Serial.print("      ");
  Serial.print("output_Y: ");
  Serial.print(Output_Y);
  Serial.print("\r\n");
  delay(100);
```

Figure 4.18 : Main program

4.11 Conclusion

In this last chapter, we have explained the different steps that allowed us to realize a magnetic suspension system, these components used and their tasks, we also presented a general description of the Arduino program implemented on the electronic board and the other important components.

General conclusion

The objectives of the project were to make the study and realization as well as the script necessary for the operation of the control system.

At the beginning of this work. We provided a general study on magnetic suspension and mentioned a definition of the topic, divided the different types of magnetic suspension, as well as its different uses. also presented the most important mathematical equations that we need to study a magnetic system, we found that it is impossible for a static system to stably levitate against gravity using only paramagnetic materials. It needs a supportive control system to achieve stability

Next, this work addressed one of the artificial intelligence-based control systems that is fuzzy logic controller (FLC) is an attractive alternative to existing classical or modern controllers for designing controller the nonlinear control systems. The fuzzy logic can stabilize the system efficiently and accurately.

The major downside of fuzzy logic control is the lack of a systematic method.

The third chapter deals with the control aspects of magnetic levitation system using fuzzy logic controller (FLC). First, he presented modeling of magneticlevitationsystem, where he presented the most famous models and extracted mathematical equations for these systems. Next, he presented the controller designs, which are PID and fuzzy logic control, and the results showed that Fuzzy logic control has better tracking as compared with the PID controller.

In the end, we presented a model for a magnetic flight system, where we explained the principle of its work. We also defined the various elements used and the steps for making this system.

Unfortunately, the magnetic suspension system did not work perfectly, and this is due to several factors, the most important of which is: the most important reason is the difficulty in obtaining the electronic components, as I ordered them from China, and it took three months to arrive, and the pieces were not original. The magnets were very weak and the error rate of the sensors was very large. This is difficult to control in suspending.

Also, the difficulty of communicating with the supervised professor and the closure of universities due to Covid 19pandemic made it more difficult to achieve the project because it needs laboratory work, but I assure that this model is successful based on Japanese studies and would have worked in the appropriate conditions.

As perspectives, we suggest to control the magnetic suspension system with other methods of the artificial intelligence such Neural Networks or Neuro-Fyzzy

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