

الآية

(وَقُلْ اَعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ وَسَتُرَدُّونَ إِلَىٰ عَالَمٍ

الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُمْ بِمَا كُنْتُمْ تَعْمَلُونَ)

صدق الله العظيم

سورة التوبة الآية 105.

Abstract

The main objective of this thesis is to design a fuzzy PID controller of a longitudinal autopilot for a Transport Aircraft. We design the self-tuning PID parameters so as to improve the system response and performance, to reduce the error and cost, and to make a PID controller more reliable for industrial processes.

It is assumed that the longitudinal aircraft motion is a short period of motion. We examine the PID fuzzy controller using MATLAB/Simulink toolbox. The simulation shows that the self-tuning PID fuzzy controller realize a good dynamic behavior of the pitch-attitude autopilot and give a better performance compare with a conventional PID controller.

المستخلص

إن الهدف الرئيسي لهذه الأطروحة هو تصميم متحكم ضبابية نسبية تكاملية تفاضلية لنظام طيار آلي طولي لطائرة تجارية نفثة. قمنا بتصميم الضبط الذاتي للمتحكم الضبابية النسبية التكاملية التفاضلية وذلك لتحسين إستجابة وأداء المنظومة، ولتقليل الخطأ والتكلفة، ولجعل المتحكم النسبية التكاملية التفاضلية أكثر موثوقية للعمليات الصناعية.

تم افتراض أن حركة الطائرة هي فترة الحركة القصيرة. وقمنا بمحاكاة تصميم المتحكم الضبابية النسبية التكاملية التفاضلية باستخدام مختبر الرياضيات\رابط المحاكاة.

المحاكاة بينت أن الضبط الذاتي للمتحكم الضبابية النسبية التكاملية التفاضلية حقق سلوك ديناميكي جيد لنظام الطيار الآلي الطولي وأعطى أداء أفضل مقارنة بالمتحكم النسبية التكاملية التفاضلية التقليدية.

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Who assisted and encouraged us throughout the period of our thesis, her patience and flexibility toward us helped us to gain knowledge in this new field of research and we highly grateful of her. She was our inspiration for doing our project, we will always remember her and appreciate very much her support.

- ❖ To aviation engineering department.
- ❖ To other provided much time and efforts to see this project to completion.

Dedication

We dedicate these humble efforts . . .

To who suckled me the love and tenderness . . .

To symbol of love and healing balm . . .

To the heart as pure in white . . .

My mother be loved.

To who taught me tender without waiting . . .

To whom I carry his name proudly . . .

To big heart . . .

My dear father.

To the pure hearts and sinless souls . . .

To basils my life . . .

My sisters and brothers.

To all family and friend and teachers.

PROJECT GROUP.

Abbreviation

CE	Change of Error
COG	Center of Gravity
E	Error
FIS	Fuzzy Inference System
MIMO	Multiple input multiple outputs
PD	Proportional-Derivative
PI	Proportional-Integral
PID	Proportional-Integral-Derivative
SISO	Single input single output

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Chapter 1

Introduction

1.1 Overview

Control system is a device that manages commands, directs or regulates the behavior of other devices or systems.

There are two common classes of control system:

- i. Open loop control system.
- ii. Closed control system.

In open loop system, the output generated not based on inputs as in the block diagram in figure (1-1), its operation is very simple, and when an input signal directs the control element to respond, an output will be produced.[1]

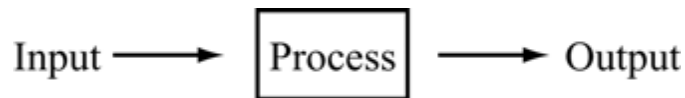


Figure 1-1: Open Loop Control System

The output of closed loop system is taken into considerations and corrections are made based on feedback as in figure (1-2), feedback is a special feature of a closed loop control system which is compares the output with the expected result, then it takes appropriate control action to adjust the input signal. A closed loop system also called a feedback control system.

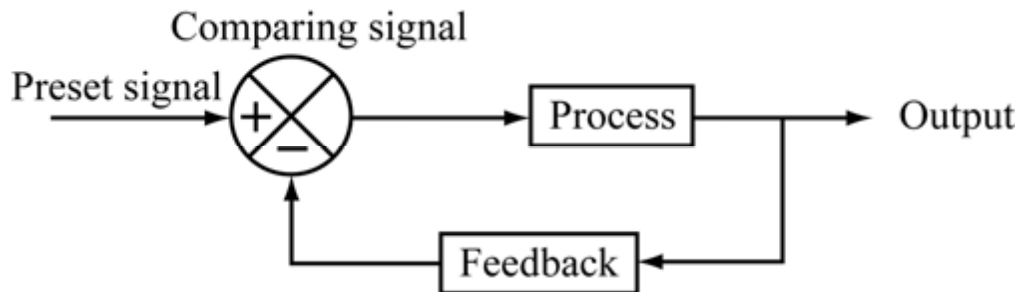


Figure 1-2: Feedback Control System

A control system in an aircraft is a collection of mechanical and electronic equipment that allows the aircraft to be flown with exceptional precision and reliability. These are flight control surfaces with the respective cockpit controls connected with each other by means of mechanical,

hydraulic or electrical linkage. These systems are necessary to control aircraft directions and aircraft speed.[2]

1.1.1 Control surfaces

The aircraft have three axes upon which it move: left and right, forward and backward, up and down. Their names are longitudinal axis, lateral axis and vertical axis as shown in figure (1-3). The longitudinal axis from the nose of the aircraft to the tail, the motion around it called rolling. The lateral axis from the right wing tip to left wing tip, the motion around it called pitching. The vertical axis rubbing vertically through the center of the aircraft, the motion around it called yawing.

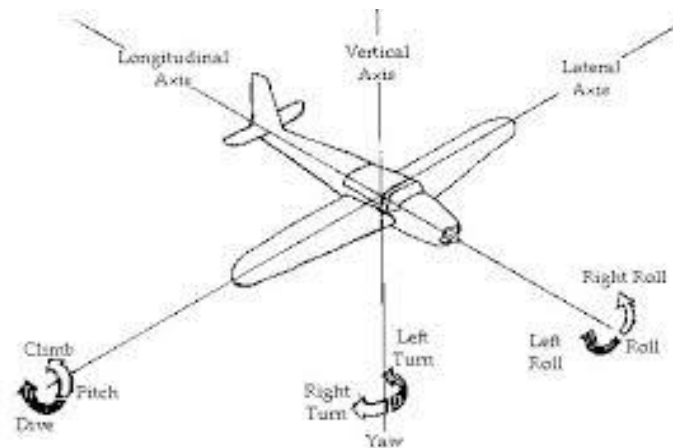


Figure 1-3: Axis of Aircraft

There are three main control surfaces in aircraft, which control an aircraft motions:

- 1- Rudder: is contributing yawing moment around directional axis, it located on the vertical stabilizer at the trailing edge.
- 2- Elevators: is contributing pitching moment around lateral axis, they located on the horizontal stabilizer.
- 3- Ailerons: is contributing rolling moment around longitudinal axis, they mounted at the trailing edge of the wing.

Control surfaces are controlled by the pilot and an autopilot used to relieve human pilot during cruise mode.[3]

An autopilot is a mechanical, electrical, or hydraulic system used in an aircraft. Autopilot performs functions more rapidly and with greater precision than the human pilot in addition to control does various types of aircraft and spacecraft.

An autopilot is unique pilot. It must provide smooth control and avoid sudden and erratic behavior. The intelligence for control must come from sensors such as gyroscopes, accelerometers, altimeters, airspeed indicators, automatic navigators, and various types of radio-controlled data links. The autopilot supplies the necessary scale factors, dynamics (timing), and power to convert the sensor signals into control surface commands. These commands operate the normal aerodynamic controls of the aircraft.

Fuzzy logic, which is a branch of artificial intelligence that deals with reasoning algorithms, used to emulate human thinking and decision making in machines, these algorithms are used in applications where process data cannot be represented in binary form.

The benefits of using fuzzy logic in PID controller are cheaper to develop and they cover a wider range of operating condition.[4]

1.1.2 Controllers

The controllers used to modify the behavior of a system so as it behaves in a specific desirable way over a time. For an example, we want the speed of a car on a highway to remain as close as possible to 60 miles per hour in spite of possible hills or adverse wind; or we may want an aircraft to follow a desired altitude, heading, and velocity profile independent of wind gust.

Proportional-Integral-Derivative controller (PID controller) is common and effective in cases such as this. PID controller is miniature part of embedded system, it operates the majority of the control system on the world, and it's used for wide range of problems like (motor drive, automotive, flight control, instrumentation). Tuning the parameters of the PID controller is very difficult, poor robustness and difficult to achieve optimal state under field condition in the actual production.[5]

1.1.3 Previous studies

There are many studies on this field such as:
-Stephen Chiu made a study in using fuzzy logic in control applications.

-GaddamMallesham and AkulaRajani made a study at automatic tuning of PID controller using fuzzy logic.

-Mr.TusharUpalanchiwer, Prof.A.V.Sakhare made a study at implementation of PID use fuzzy logic.

1.2 Statement of problem

Design a self-tuning PID fuzzy controller for a longitudinal Autopilot.

1.3 Aims & Objectives

1.3.1 Aim

Design and implementation of PID controller using fuzzy logic.

1.3.2 Objectives

- Build PID controller reliable for industrial and reduce cost.
- Analysis system response, performance and reduce the error signal of system.
- Use for perform high-level control function.

1.4 Proposed Solution

The proposed solution consists in the design and evaluation of the PID Fuzzy controllers using the Fuzzy Logic Toolbox of Matlab.

1.5 Motivation

A substantial portion of the literature on fuzzy control deals with the use of fuzzy rules to implement non-linear proportional- integral- derivative (PID) type control. Fuzzy logic is used mostly to handle high- level control functions that traditional control methods do not address.

1.6 Contribution of the Thesis

In this thesis, the design of fuzzy logic supervising a PID control system in a longitudinal Autopilot for a Business jet Aircraft will proposed. We examine the PID fuzzy controller to

make PID controller reliable for industrial & reduce the cost, for improve the system response, performance & reduce the error, and for evaluating controller performance.

1.7 Methodology

The design of Self-Tuning Fuzzy PID controller allows better performance than the conventional PID controller, which shall improve the system reliability and response of the system. This thesis presented the design step below:

First for the conventional PID controller the tuning of the parameters was done by using Ziegler-Nichols method, then the transfer function was found based on the modelled aircraft (appendix). And the simulink block diagram was designed to control on the pitch of the longitudinal autopilot. The result of the system response was shown.

Secondly for the Self-Tuning Fuzzy PID controller, the Fuzzy Inference System was designed based on the inputs e and ce , and outputs K_i , K_d and K_p . Then the FIS design used in tuning the parameter of the PID controller and the simulink block diagram was designed so as to improve the response of the longitudinal autopilot in controlling the pitch motion.

1.8 Outline of the Thesis

By considering the literature- review, chapter 1 will discuss the objectives, statement of problem and methodology. The overview of the PID controller and their tuning parameters will be the subject of chapter 2. Chapter 3 will provide the design of longitudinal Autopilot focusing on the model under study. The fuzzy logic will discuss in chapter 4 in order to design the PID fuzzy controller for the model Aircraft. Chapter 5 will deal with the design process of controlling the longitudinal Autopilot for Transport Aircraft. The design process includes the design of PID controller using the fuzzy sets and fuzzy rules. In chapter 6, the results are directly states from the statement of problem towards the opportunities given in this thesis. Discussion, conclusion & recommendations will provide also in chapter 6.

Chapter Two

PID Controller

2.1 Introduction

Controller is a device, historically using mechanical, hydraulic pneumatic or electronic techniques often in combination but more recently in the form of microprocessor or computer which monitors and physically alters the operating conditions of a given dynamical systems. Typical applications of controllers are to hold settings for temperature, pressure, flow or speed.

2.1.1 Input and control variables

A system can be described either as MIMO (Multiple Input Multiple Output) system having multiple inputs and outputs therefore requiring more than one controller; or as a SISO (Single Input Single Output) system consisting of a single input and single output hence having only single controller. Depending a set-up of the physical (or non-physical) system, adjusting the systems input variable (assuming it is SISO) will affect the operating parameter.

Upon receiving the error signal that marks the disparity between the desired value (set point) and the actual output value. The controller will then attempt to regulate controller output behavior. The controller achieves this by either attenuating or amplifying the input signal to the plant so that the output is returned to the set point.

2.1.2 Types of controllers

There are two basic types of controller: feedback and feed-forward controller.

2.1.2.1 Feed-forward

Feed-forward control can avoid the slowness of feedback control. With feed-forward control the disturbance are measured and accounted before they have time to affect the system.

2.1.2.2 Feed-back

The input to a feedback controller is the same as what it is trying to control. The controller variable is 'fed back' in to the controller.[6]

2.2 PID controller

A **Proportional-Integral-Derivative** controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired set point as shown in figure (2-1).

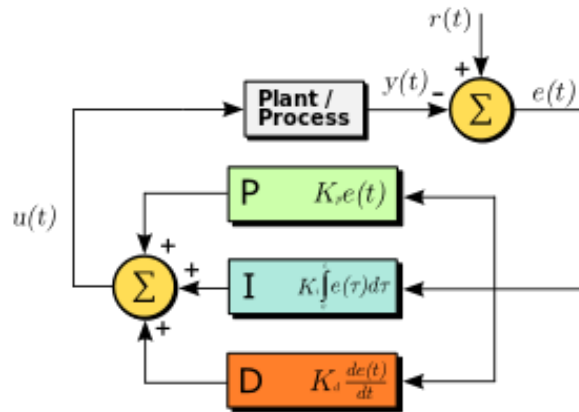


Figure 2-1: PID Parameters

The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative value, denoted P, I, and D simply. These values can be interpreted in terms of time. P (proportional) depends on the present error, I (Integral) depends on the accumulation of past errors, and D (Derivative) is a prediction of future errors, based on current rate of change.

By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point, and the degree of system oscillation.

A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. In process control today, more than 95% of the control loops are of PID type, most loops are actually PI control. PID controllers are today found in all areas where control is used. The controllers come in many different forms. There are stand-alone systems in boxes for one or a few loops, which are manufactured by the hundred Thousands yearly.

PID control is an important ingredient of a distributed control system. The controllers are also embedded in many special-purpose control systems. PID control is often combined with logic, sequential functions, selectors, and simple function blocks to build the complicated automation systems used for energy production, transportation, and manufacturing.

Many sophisticated control strategies, such as model predictive control, are also organized pyramidal. PID control is used at the lowest level; the multivariable controller gives the set points to the controllers at the lower level.

Practically all PID controllers are based on microprocessors. This has given opportunities to provide additional features like automatic tuning, gain scheduling, and continuous adaptation.[7]

2.2.1 PID theory

The PID scheme is named after its three correcting terms (K_p, K_i, K_d), whose constitutes the manipulated variable (mv). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining $u(t)$ as the controller output, the final form of the PID algorithm is:

$$u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + k_d \frac{d}{dt} e(t) \dots \quad (2-1)$$

Where:

K_p : Proportional gain.

K_i : Integral gain.

K_d : Derivative gain.

e : Error= $SP-PV$

SP : set point.

PV : actual measured value.

t : time or instantaneous time.

τ : variable of integration; takes on values from time 0 to the present t .

2.2.2 Proportional term

The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p , called the proportional gain constant.

The proportional term is given by:

$$P_{out} = K_p * e(t) \quad (2-2)$$

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller.

If the proportional gain is too low, the control action may be too small when responding to system disturbances. Tuning theory and industrial practice indicate that the proportional term should contribute the bulk of the output change.

A proportional controller generally operates with a steady-state error, referred to as drop or offset. The drop is proportional to the process gain and inversely proportional to proportional gain. Droop may be mitigated by adding a compensating bias term to the set point or output, or corrected dynamically by adding an integral term.

2.2.3 Integral term

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the summation of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain (K_i) and added to the controller output.

The integral term is given by:

$$I_{out} = K_i \int_0^t e(\tau) d\tau \quad (2-3)$$

The integral term accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the set point value.

2.2.4 Derivative term

The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain K_d . The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain K_d .

The derivative term is given by:

$$D_{out} = K_d \frac{d}{dt} e(t) \quad (2-4)$$

Derivative action predicts system behavior and thus improves settling time and stability of the system. It seldom used in practice though-by one estimate in only 20% of the deployed controller.

2.2.5 PI controller

A PI Controller (proportional-integral controller) is a special case of the PID controller in which the derivative (D) of the error is not used.

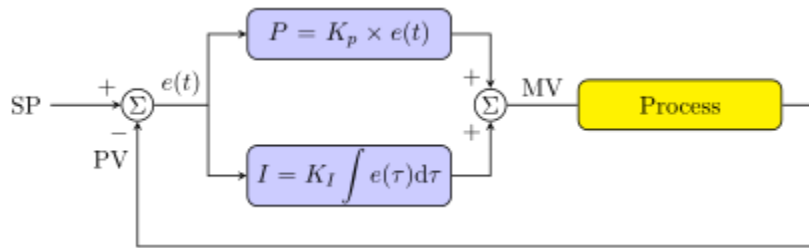


Figure 2-2: PI Controller

The controller output is given by:

$$K_p \Delta + K_i \int \Delta dt \quad (2-5)$$

Where Δ is the error or deviation of actual measured value (**PV**) from the set point (**SP**).

$$\Delta = SP - PV \quad (2-6)$$

A PI controller can be modeled easily in software such as Simulink or Xcos using a "flow chart" box involving Laplace operators. The lack of derivative action may make the system more steady in the steady state in the case of noisy data. This is because derivative action is more sensitive to higher-frequency terms in the inputs.

Without derivative action, a PI-controlled system is less responsive to real (non-noise) and relatively fast alterations in state and so the system will be slower to reach set point and slower to respond to perturbations than a well-tuned PID system may be.

2.2.6 PD Controller

Proportional plus rate describes a control mode in which a derivative section is added to a proportional, this derivative section responds to the rate of change of the error signal not the

amplitude; this derivative responds to the rate of change the instant it starts, this causes the controller output to be initially larger in direct relation with the error signal rate of change.

The higher the error signal rate of change, the sooner the final control element is positioned to the desired value. The added derivative action reduces initial overshoot of the measure variable, and therefore aids in stabilizing the process sooner.

PD control for the process transfer function is:

$$P(s) = k/(1 + \tau s) \quad (2-6)$$

Apparently is not very useful, since it cannot reduce the steady state error to zero but for higher order processes it can be shown that the stability of the closed loop system can be improved using PD controller.[8]

2.3 Tuning the parameter

Tuning a control loop is the adjustment of its control parameters (proportional band/gain, integral gain/reset, derivative gain/rate) to the optimum values for the desired control response. Stability (no unbounded oscillation) is a basic requirement, but beyond that, different systems have different behavior, different applications have different requirements, and requirements may conflict with one another.

PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for loop tuning, and more sophisticated techniques are the subject of patents; this section describes some traditional manual methods for loop tuning.

Designing and tuning a PID controller appears to be conceptually intuitive, but can be hard in practice, if multiple (and often conflicting) objectives such as short transient and high stability are to be achieved. PID controllers often provide acceptable control using default tunings, but performance can generally be improved by careful tuning, and performance may be unacceptable with poor tuning. Usually, initial designs need to be adjusted repeatedly through computer simulations until the closed-loop system performs or compromises as desired.

Some processes have a degree of nonlinearity and so parameters that work well at full-load conditions don't work when the process is starting up from no-load; this can be corrected by gain scheduling (using different parameters in different operating regions).

Table 2.1: Characteristic of Parameters of PID

Parameter	Rise time	Settling time	Steady state error	Overshoot
K_p	Decrease	Small change	Decrease	Increase
K_i	Decrease	Increase	Eliminate	Increase
K_d	Minor change	Decrease	No effect	Decrease

There are many methods in tuning the parameter of controller, few shows below:

2.3.1 Controller structure

In the following, the controller is assumed to have the parallel structure, defined as

$$H_c(s) = K_p(1 + \frac{1}{s\tau_I} + \tau_D s) \quad (2-7)$$

2.3.2 Trial and error

Trial and error is an easy way of tuning a controller, but satisfactory performance is not guaranteed, and it takes a lot of time. Often, the response y to a square wave or step r is taken as the indicator of the quality of the controller. Overshoot, undershoot and rise time can be taken as performance criteria. An example of such a procedure is given in Ellis. So-called zone-based tuning is used, which means that the low and high frequency parts of the controller can be tuned separately, starting with the high frequency part. For a PID controller, this means that first the P- and D-action are tuned and then the I-action.

Here, the performance criterion is the overshoot of the step response, which is related to the stability margin of the control system. A high stability margin generally leads to low overshoot, and low stability margins to a more oscillatory behavior. This method is easy to use for process operators, since little or no knowledge of the controlled process is required. The numerical values in the procedure are rules of thumb, based on experience. The disadvantage is that little can be said about the robustness of the system. Further, many iteration steps may be needed before the final settings are obtained.

2.3.4 Ziegler-Nichols Method

In 1942, Ziegler and Nichols presented two classical methods to tune a PID-controller. These methods are still widely used, due to their simplicity. In their first method, the controller settings are based on the two parameters θ and a . They based the choice for the controller parameters on simulation results for several processes, by adjusting the controller parameters until the response showed a decay ratio d of 0.25. A quarter decay corresponds to a relative damping $\zeta=0.21$, which they considered a good compromise between quick response and adequate stability margins. The proposed Ziegler-Nichols settings are shown in table (2-2).

Table 2.2: The Proposed Ziegler-Nichols setting

Controller Type	K_p	T_i	T_d
P	$1/a$	-	-
PI	$0.9/a$	3.33θ	-
PID	$1.2/a$	2θ	0.5θ

The advantage of the Ziegler-Nichols method is that the tuning rules are very simple to use. Disadvantages are:

- Further fine tuning is needed.
- Controller settings are aggressive, resulting in large overshoot and oscillatory responses.
- Poor performance for processes with a dominant delay.
- Closed loop very sensitive to parameter variations.
- Parameters of the step response may be hard to determine due to measurement noise.[9]

2.4 Summary

The PID controller can thus be said to be the “bread and butter of control engineering. It is an important component in every control engineer’s Toolbox. PID controllers have survived many changes in technology, from mechanics and pneumatics to microprocessors via electronic tubes, transistors, integrated circuits. The microprocessor has had a dramatic influence on the PID controller. Practically all PID controllers made today are based on microprocessors. This has

given opportunities to provide additional features like automatic tuning, gain scheduling, and continuous adaptation.

Chapter 3

Autopilot

3.1 Introduction

The autopilot is a part of automatic flight control system used to perform few tasks. In the early days of transport aircraft, aircraft required the continuous attention of a pilot in order to fly in safe manner. This created very high demands on crew attention and high fatigue. The autopilot is designed to performed few tasks mentioned early. The first autopilot was developed by Sperry Corporation in 1912 using gyros to sense the deviation of the aircraft from the desired attitude and servo motor to activate the elevators and ailerons easy to built under the direction of Dr. E. A. Sperry. The apparatus, called Sperry Airplane Stabilizer, installed in the Curtis Flying Boat.

The autopilot connected to a gyroscopic attitude indicator and magnetic compass to hydraulically operated rudder, elevator and ailerons. It permitted the aircraft to fly straight and level on a compass course without pilot's attention, thus covering more than 80 percent of the total pilot's workload on a typical flight.

3.2 Flight Control System

A flight control system is either a primary or secondary system. Primary flight controls provide longitudinal motion (pitch), directional motion (yaw), and lateral motion (roll) control of the aircraft. Secondary flight controls provide additional lift during take-off and landing, and decrease aircraft speed during flight, as well as assisting primary flight controls in the movement of the aircraft about its axis.

All system consists of the flight control surfaces, the respective cockpit controls, connecting linkage, and necessary operating mechanisms. in order for an aircraft to reach its destination, the forces of flight have to be precisely manipulated. To do this, the aircraft has control surfaces which can direct airflow in very specific ways. There are three types of flight control systems as discussed below.

3.2.1 Mechanical flight control systems

Mechanical flight control systems are the most basic designs. They are basically unboosted flight control systems. They were used in early aircraft and currently in small airplanes where the aerodynamic forces are not excessive. The flight control surfaces (ailerons, elevators, and rudder) are moved manually through a series of push-pull rods, cables, bell cranks, and sectors. Since an increase in control surface area in bigger and faster aircraft leads to a large increasing in the forces needed to move them. In this case, complicated mechanical arrangements are used to extract maximum mechanical advantage in order to make the forces required bearable to the pilots. This arrangement is found on bigger or higher performance propeller aircraft.

Some mechanical flight control systems use servo tabs that provide aerodynamic assistance to reduce complexity. Servo tabs are small surfaces hinged to the control surfaces. The mechanisms move these tabs; aerodynamic forces in turn move the control surfaces reducing the amount of mechanical forces needed. This arrangement was used in early piston-engine transport aircraft and early jet transports. The primary flight control system is illustrated in figure (3-1).

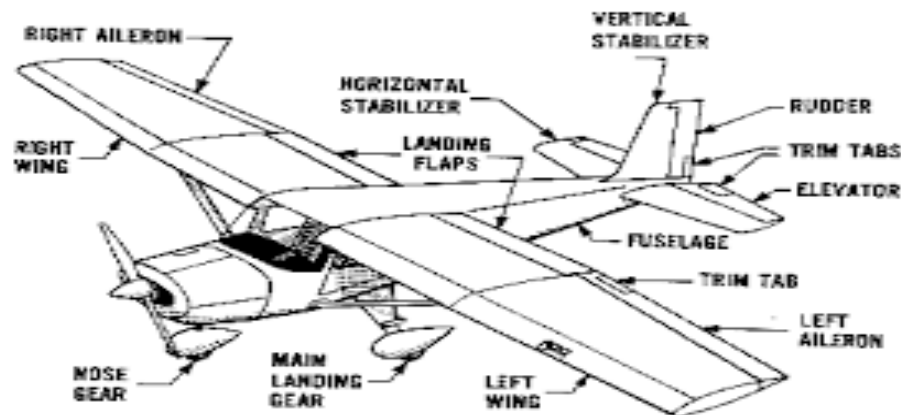


Figure 0-1: Primary Flight Control System

3.2.2 Hydro-mechanical flight control systems

They are power boosted flight control systems. The complexity and weight of a mechanical flight control systems increases considerably with size and performance of the airplane. Hydraulic power overcomes these limitations. With hydraulic flight control systems aircraft size and performance are limited by economics rather than a pilot's strength. In the power-boosted system, a hydraulic actuating cylinder is built into the control linkage to assist the pilot in moving the control surface. A hydraulic flight control systems has 2 parts:

- Mechanical circuit
- Hydraulic circuit

The Mechanical circuit links the cockpit controls with the hydraulic circuits. Like the mechanical flight control systems, it is made of rods, cables, pulleys, and sometimes chains. The hydraulic circuit has hydraulic pumps, pipes, valves and actuators. The actuators are powered by the hydraulic pressure generated by the pumps in the hydraulic circuit. The actuators convert hydraulic pressure into control surface movements. The servo valves control the movement of the actuators.

The pilot's movement of a control causes the mechanical circuit to open the matching servo valves in the hydraulic circuit. The hydraulic circuit powers the actuators which then move the control surfaces. These Powered flight controls are employed in high performance aircraft, and are generally of two types: power assisted and power operated.

Both systems are similar in basic forms but to overcome the aerodynamic loads forces are required, which decides the choice of either of the above system.

3.2.3 Fly by wire (FBW) flight control systems

Fly-by-wire is means of aircraft control that uses electronic circuits to send inputs from the pilot to the motors that move the various flight controls on the aircraft. There are no direct hydraulic or mechanical linkages between the pilot and the flight controls. Fly-by-wire, that is, the complete replacement of the mechanical linkages between the pilot's stick and the control surface actuators by electrical signal wires, offers a convenient and logical solution to many of the control system problems associated with modern high performance aircraft and aerospace vehicles.

Mechanical and hydraulic flight control systems are heavy and require careful routing of flight control cables through the airplane using systems of pulley and cranks. Both systems often require redundant backup, which further increases weight. The advantages of FBW system are:

1. Provides high-integrity automatic stabilization of the aircraft to compensator the loss of natural stability and thus enables a lighter aircraft with a better overall performance.
2. Makes the ride much smoother than one controlled by human hands. The capability of FBW systems to maintain constant flight speeds and altitudes over long distances is

another way of increasing fuel efficiency. The system acts much like cruise controls on automobiles: less fuel is needed if throttles are untouched over long distances.

3. More reliable than a mechanical system because of fewer parts to break or malfunction. FBW is also easier to install, which reduces assembly time and costs. FBW maintenance costs are lower because they are easier to maintain and troubleshoot, and need fewer replacement parts.
4. Electrical wires for a flight control system takes up less space inside fuselages, wings, and tail components. This gives designers several options. Wings and tail components can be designed thinner to help increase speed and make them aerodynamically cleaner, and also to reduce weight. Space once used by mechanical linkages can also be used to increase fuel capacities to give the aircraft greater range or payload.[4]

3.3 Aircraft Motion

In flight, any aircraft rotate about its center of gravity a point which is the average location of the mass of the aircraft. An aircraft in flight is free to rotate in three dimensions: pitch, nose up or down about an axis running from wing to wing; yaw, nose left or right about an axis running up or down; and roll, rotation about an axis running from nose to tail. The axes are alternatively designed as lateral, vertical and longitudinal.

3.3.1 Elevator-Pitch motion

As the name implies, the elevator helps “elevate” the aircraft. It is usually located on the tail of the aircraft and serves two purposes. The first is to provide stability by producing a downward force on the tail. Airplanes are traditionally nose-heavy and this downward force is required to compensate for that. The second is to direct the nose of the aircraft either upwards or downwards, known as pitch, in order to make the airplane climb and descend.

3.3.2 Ailerons –Roll motion

The ailerons are located at the rear of the wing, one on each side. They work opposite to each other, so when one is raised, the other is lowered. Their job is to increase the lift on one wing, while reducing the lift on the other. By doing this, they roll the aircraft sideways, which allows the aircraft to turn. This is the primary method of steering a fixed-wing aircraft

3.3.3 Rudder-Yaw motion

The rudder is located on the tail of the aircraft. It works identically to a rudder on a boat, steering the nose of the aircraft left and right. Unlike the boat however, it is not the primary method of steering. Its main purpose is to counteract the drag caused by the lowered aileron during a turn. This adverse yaw, as it is known, causes the nose of the airplane to point away, or outwards, from the direction of the turn. The rudder helps to correct this by pushing the nose in the correct direction, maintaining what is known as coordinated flight.[10]

3.4 Components of Autopilot

The basic components of the autopilot are shown in the figure (3-2). Aircraft motion is sensed by a gyro, which transmits a signal to a computer the computer commands a control servo to produce aerodynamic forces to remove the sensed motion. The computer may be a complex digital computer, an analog computer (electrical or mechanical), or a simple summing amplifier, depending on the complexity of the autopilot. The control servo can be a hydraulically powered actuator or an electromechanical type of surface actuation. Signals can be added to the computers that supply altitude commands or steering commands. For a simple autopilot, the pitch loop controls the elevators and the roll loop controls the aileron. A directional loop controlling the rudder may be added to provide coordinated turns.

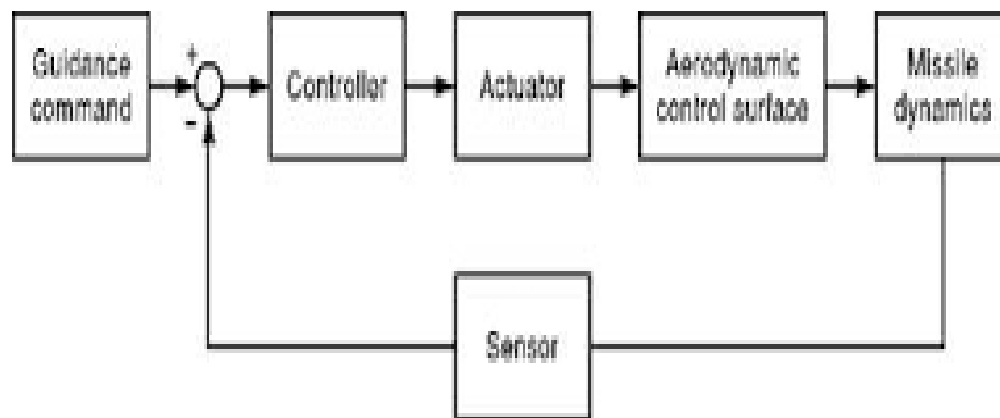


Figure 0-2: Component of Autopilot

3.5 Aircraft equation of motion

There are basic assumptions to evaluate the equations of the autopilot system:

1. The aircraft is a rigid body.
2. The aircraft is symmetric.
3. The mass of the aircraft is constant at the moment of application of control action.
4. The center of gravity is at the center of mass.
5. The origin of the aircraft axis is at the center of gravity.
6. The earth axis is frame of reference.

Based on Newton's second law which states; the summation of all forces acting on the body must be equal to the momentum time rate of change of the body and the summation of moments acting on a body must be equal to the tie rate of change of the angular momentum of that body.

$$\sum F = \frac{d}{dt}(mV_t)]_i \quad (3-1)$$

$$\sum M = \frac{dH}{dt}]_i \quad (3-2)$$

Where:

F... is the force vector.

m... is the mass.

V_t ... is the total velocity

M... is the moment vector.

H... is the angular momentum.

$]_i$... is the inertial space.

The inertial space is the space where Newton's second law is applied.

$$\sum \Delta F_x = m(\dot{U} + WQ - VR) \quad (3-3)$$

$$\sum \Delta F_y = m(\dot{W} + UR - WP) \quad (3-4)$$

$$\sum \Delta F_z = m(\dot{W} + VP - UQ) \quad (3-5)$$

$$\sum \Delta \mathcal{L} = \dot{P}J_{xx} - \dot{R}J_{xz} + QR(J_{zz} - J_{yy}) - PQJ_{xz} \quad (3-6)$$

$$\sum \Delta \mathcal{M} = \dot{Q}J_{yy} - PR(J_{xx} - J_{zz}) + (P^2 - R^2)J_{xz} \quad (3-7)$$

$$\sum \Delta \mathcal{N} = \dot{R}J_{zz} - \dot{P}J_{xz} + PQ(J_{yy} - J_{xx}) + QRJ_{xz} \quad (3-8)$$

F_x, F_y and F_z are the force vector in the X axes, Y axes and Z axes respectively.

U, V and W . . . are the velocity vector in the X, Y and Z axes respectively.

P, Q and R . . . are the angular velocity vector in the X, Y and Z axes respectively.

J_{xx}, J_{yy} and J_{zz} are the inertia moment in the X , Y and Z axes respectively.

J_{xz}, J_{yz} and J_{xy} is the cross coupling inertia moment.

3.5.1 Linearization and Separation of the Equations of Motion

A study of Equations from. (3-3) to (3-8) shows that it takes six simultaneous nonlinear equations of motion to completely describe the behavior of a rigid aircraft. In this form, a solution can be obtained only by the use of analog or digital computers or by manual numerical integration. In most cases, however, by the use of proper assumptions the equations can be broken down into two sets of three equations each and these linearized to obtain equations amenable to analytic solutions of sufficient accuracy.

The six equations are first broken up into two sets of three simultaneous equations. To accomplish this, the aircraft is considered to be in straight and level unaccelerated flight and then to be disturbed by deflection of the elevator. This deflection applies a pitching moment about the OY axis, causing a rotation about this axis which eventually causes a change in F_x and F_z , but does not cause a rolling or yawing moment or any change in F_y . This leaves

$$\sum \Delta F_x = m(\dot{U} + WQ) \quad (3-9)$$

$$\sum \Delta F_z = m(\dot{W} - UQ) \quad (3-10)$$

$$\sum \Delta \mathcal{M} = \dot{Q}I_{yy} \quad (3-11)$$

Eqs from (4-9) to (4-11) is called longitudinal equations for $P=R=Q=0$.

3.6 Longitudinal Autopilot

3.6.1 Displacement Autopilot

The simplest form of autopilot, which is the type that first appeared in aircraft and is still being used in some of the older transport aircraft, is the displacement-type autopilot. This autopilot was designed to hold the aircraft in straight and level flight with little or no maneuvering capability. For this type of autopilot the aircraft is initially trimmed to straight and level flight, the reference aligned, and then the autopilot engaged.

If the pitch attitude varies from the reference, a voltage *egis* produced by the signal generator on the vertical gyro. This voltage is then amplified and fed to the elevator servo. The elevator servo can be electromechanical or hydraulic with an electrically operated valve. The servo then positions the elevator, causing the aircraft to pitch about the Y axis and so returning it to the desired pitch attitude.

The elevator servo is, in general, at least a second-order system; but if properly designed, its natural frequency is higher than that of the aircraft. If the damping ratio is high enough, the elevator servo can be represented by a sensitivity (gain) multiplied by a first-order time lag. Representative characteristic times vary from 0.1 to 0.03 sec. The transfer function used to represent the aircraft can be the complete three-degree-of freedom longitudinal transfer function or the transfer function of the short-period approximation. The choice depends on what characteristic of the aircraft behavior is being studied.

There is one disadvantage of this system, from a servo point of view; that is, it is a Type 0 system this means that there are no integrations in the forward loop. Thus if some fixed external moment were applied, resulting from a change in trim, for example, there would have to be an error in δ to generate a voltage to drive the elevator servo, thus producing an elevator deflection to balance the interfering moment. This, then, would require the pilot to make occasional adjustments of the reference to maintain the desired flight path.

Although the displacement autopilot with rate feedback adequately controls a jet transport, it is desirable to obtain a Type 1 system to eliminate the steady-state error for a step input. This fact plus the desirability for more maneuverability, especially in fighter aircraft, has led to the pitch orientation control system with control stick steering.

3.6.2 Pitch Orientation Control System

The pitch orientation control system has as its input a desired pitch rate; such an input, plus the desire to obtain a Type 1 system, which calls for integration in the forward loop, makes it advisable to use an integrating gyro as the command receiver. The necessity for the rate gyro depends upon the characteristics of the system. If this system is to be used to control the attitude of the aircraft, an altitude or Mach hold control system can be used for the third and outer loop and thus provide the $\dot{\theta}_{comm}$ signal. The command signal can also come from the pilot.

The pilot's input might come from a so-called "maneuver stick," a small control stick which, when moved, positions a potentiometer and thus produces a voltage. Such a system is referred to as a fly-by-wire control system. The introduction of component redundancy and digital flight control systems, capable of detecting sensor or other component failure, has made fly-by-wire control systems practical. In these systems the software detects the failure of any component, isolates the failed component, and transfers operation or control to a redundant operational component.

3.7 Lateral Autopilot

As most aircraft are spirally unstable, there is no tendency for the aircraft to return to its initial heading and roll angle after it has been disturbed from equilibrium by either a control surface deflection or a gust. Thus the pilot must continually make corrections to maintain a given heading. The early lateral autopilots were designed primarily to keep the wings level and hold the aircraft on a desired heading.

A vertical gyro was used for the purpose of keeping the wings level, and a directional gyro was used for the heading reference. This autopilot had only very limited maneuvering capabilities. Once the references were aligned and the autopilot engaged, only small heading changes could be made. This was generally accomplished by changing the heading reference and thus yawing the aircraft through the use of the rudders to the new heading.

Obviously such a maneuver was uncoordinated and practical only for small heading changes, due to the lack of maneuverability and the light. Damping characteristic of the Dutch roll oscillation in high-performance aircraft, this autopilot is not satisfactory for our present-day aircraft. Present day lateral autopilots are much more complex. In most cases it is necessary to provide artificial damping of the Dutch roll. Also, to add maneuverability, provisions are

provided for turn control through the deflection of the aileron, and coordination is achieved by proper signals to the rudder.

3.7.1 Lateral Equations of Motion

In this section the three lateral equations are linearized and combined with the aerodynamic terms to yield the lateral equations of motion for the rigid aircraft. From these equations, the lateral modes can be determined and the various transfer functions for both rudder and aileron input derived and analyzed. Before deriving the lateral equations of motion, it is necessary to define the sideslip angle. As in the longitudinal case, stability axes are used. If during the perturbations from equilibrium the aircraft X axis is displaced about the Z axis from the aircraft velocity vector, a sideslip angle will be generated.

As mentioned early that there are certain assumptions which, if employed, permit the decoupling of the six equations of motion. The three lateral equations can be obtained from Eq. (3-3) to (3-5):

$$\sum \Delta F_y = m(\dot{W} + UR - WP)$$

$$\sum \Delta \mathcal{L} = \dot{P}J_{xx} - \dot{R}J_{xz} + QR(J_{zz} - J_{yy}) - PQJ_{xz}$$

$$\sum \Delta \mathcal{N} = \dot{R}J_{zz} - \dot{P}J_{xz} + PQ(J_{yy} - J_{xx}) + QRJ_{xz} \quad (3-12)$$

The pitching moment equation that is neglected is also rewritten here $\sum \Delta \mathcal{M} = \dot{Q}J_{yy} - PR(J_{xx} - J_{zz}) + (P^2 - R^2)J_{xz}$ this equation contains both P and R , but if the perturbations are small, and it is assumed that P and R is so small that their products and squares can be neglected, the equations can be decoupled. This assumption was made early, and it applies here. As the equations have been decoupled, Q is assumed zero. By requiring that the equilibrium direction of the X axis be along the flight path and that there be no sideslip in equilibrium, then $V_0 = W = 0$ and $U = U_0 + u$. Then $V = D$, $W = 0$, $U = u$. As the aircraft initially is in unaccelerated flight, P_0 and R_0 must be zero. Then $P = p$ and $R = r$. Making these substitutions, Eq.(3-10)

$$\sum \Delta F_y = m(\dot{v} + U_0 r + ur)$$

$$\sum \Delta \mathcal{L} = \dot{p}I_{xx} - \dot{r}J_{xz}$$

$$\sum \Delta \mathcal{N} = \dot{r}J_{zz} - \dot{p}J_{xz} \quad [4] \quad (3-13)$$

3.8 Scope of the Thesis

Previously in this chapter discuss the Autopilot as general; our Thesis is concerned in PID controller with fuzzy logic on the longitudinal autopilot (short and long period oscillation).

3.9 Summary

Automated flight control can make a long flight easy by relieving the tedious second-by-second manipulation and control of the aircraft. Overdependence on automated flight controls can cost hard-earned aircraft handling skills, and allow losing the situational awareness important to safe flight. Automated flight controls require to study and learn the system's programming and mode selection actions.

Chapter 4

Fuzzy Logic

4.1 Introduction

A Fuzzy Logic, which is a branch of artificial intelligence that deals with reasoning algorithms, used to emulate human thinking and decision making in machines, these algorithms are used in applications where process data cannot be represented in binary form.

The idea of fuzzy logic was invented by Professor L. A. Zadeh of the University of California at Berkeley in 1965. This invention was not well recognized until Dr. E. H. Mamdani, who is a professor at London University, applied the fuzzy logic in a practical application to control an automatic steam engine in 1974, which is almost ten years after the fuzzy theory was invented.

Then, in 1976, Blue Circle Cement and SIRA in Denmark developed an industrial application to control cement kilns. That system began to operation in 1982. More and more fuzzy implementations have been reported since the 1980s, including those applications in industrial manufacturing, automatic control, automobile production, banks, hospitals, libraries and academic education. Fuzzy logic techniques have been widely applied in all aspects in today's society.[11]

To implement fuzzy logic technique to a real application requires the following three steps:

1. Fuzzification: convert classical data or crisp data into fuzzy data or Membership Functions (MFs).
2. Fuzzy Inference Process: combine membership functions with the control rules to derive the fuzzy output.
3. Defuzzification: use different methods to calculate each associated output and put them into a table: the lookup table. Pick up the output from the lookup table based on the current input during an application.

Figure (4-1) illustrates the component of the fuzzy logic system.

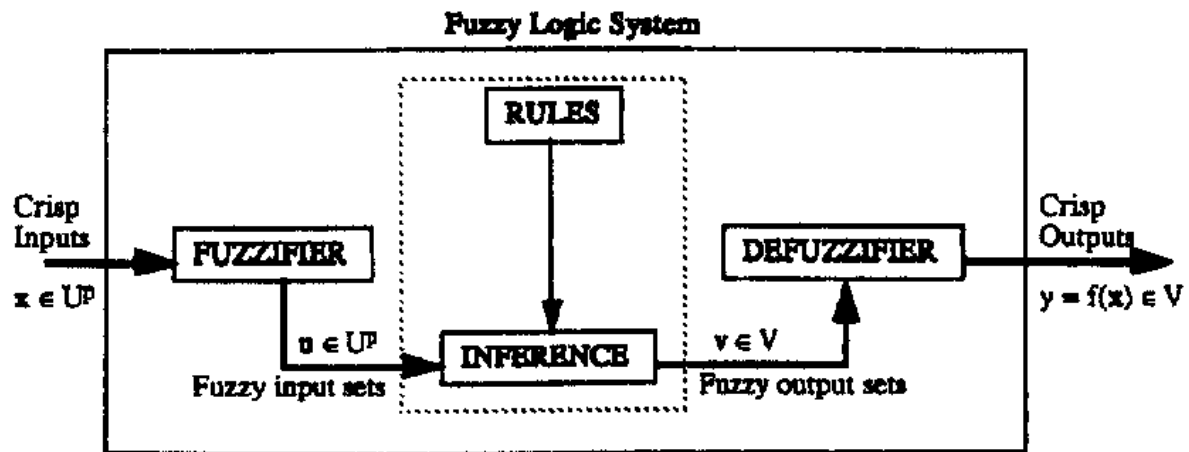


Figure 4-1: The component of Fuzzy Logic System

4.2 Fuzzy Logic Control System

During the past decade, fuzzy logic control has emerged as one of the most active and fruitful research areas in the application of fuzzy set theory, fuzzy logic and fuzzy reasoning. Many industrial and consumer products using fuzzy logic technology have been built and successfully sold worldwide. In contrast to conventional control techniques, fuzzy logic control is best utilized in complex processes that can be controlled by a skilled human operator without much knowledge of their underlying dynamics.

The basic idea behind fuzzy logic control is to incorporate the “expert experience” of a human operator in the design of a controller in controlling a process whose input-output relationship is described by a collection of fuzzy control rules (e.g. IF-THEN rules) involving linguistic variables. This utilization of linguistic variables, fuzzy control rules, and approximate reasoning provides a means to incorporate human expert experience in designing the controller.

4.2.1 Fuzzification

Fuzzification is the first step to apply a fuzzy inference system. Most variables existing in the real world are crisp or classical variables. One needs to convert those crisp variables (both input and output) to fuzzy variables, and then apply fuzzy inference to process those data to obtain the desired output.

Fuzzification involves two processes: derive the membership functions for input and output variables and represent them with linguistic variables. This process is equivalent to converting or mapping classical set to fuzzy set to varying degrees.

4.2.1.1 Fuzzy set

A set is a collection well understood and distinguishable objects of our concepts or our thinking about the collection. Fuzzy sets were introduced by Zadeh in 1965 to represent manipulate data and information possessing non statistical uncertainties. It was specifically designed to mathematically represent uncertainty and vagueness and to provide formalized tools for dealing with the imprecision intrinsic to many problems. This theory proposed making the membership function (or the values **F** and **T**) operate over the range of real numbers [0, 1].

Fuzzy set is a collection of objects in connection with expression of uncertainty of the property characterizing the objects by grades from interval between 0 and 1.

4.2.1.2 Membership function

It is clear that a fuzzy set contains elements which have varying degrees of membership in the set, and this is contrasted with the classical or crisp sets because members of a classical set cannot be members unless their membership is full or complete in that set. A fuzzy set allows a member to have a partial degree of membership and this partial degree membership can be mapped into a function or a universe of membership values.

In practice, membership functions can have multiple different types, such as the triangular waveform, trapezoidal waveform, Gaussian waveform, bell-shaped waveform, sigmoid waveform and S-curve waveform. The exact type depends on the actual applications. Assume that we have a fuzzy set A, and if an element x is a member of this fuzzy set A, this mapping can be denoted as

$$\mu_A(x) \in [0,1] \quad A = [x, \mu_A(x) | x \in X] \quad (4-1)$$

X -universe (of discourse) =set of objects

$\mu_A(x)$ is interpreted as the degree of membership of element x in fuzzy set A for each $x \in X$.

$$X = \{x_1, \dots, x_n\} \quad (4-2)$$

The fuzzy set function can be modulated by the following:

- Support set

Let A be a fuzzy subset of

X; the support of A, denoted $\text{supp}(A)$, is the crisp subset of X whose elements all have nonzero membership grades in A.

$$\text{Supp}(A) = \{x \in X | A(x) > 0\}. \quad (4-3)$$

- Normal fuzzy set

A fuzzy subset A of a classical set X is called normal if there exists an $x \in X$ such that $A(x) = 1$. Otherwise A is subnormal.

- α -cut of fuzzy set

An α -level set of a fuzzy set A of X is a non-fuzzy set denoted by $[A]^\alpha$ and is defined by $[A]^\alpha = \{t \in X | A(t) \geq \alpha\}$ if $\alpha > 0$

$$\text{Or } [A]^\alpha = \text{cl}(\text{supp}A) \text{ if } \alpha = 0 \quad (4-4)$$

Where: $\text{cl}(\text{supp}A)$ denotes the closure of the support of A.

In order to easily manipulate fuzzy sets, we are redefining the operators of the classical set

theory to fit the specific membership functions of fuzzy logic for values strictly between 0 and 1.

The basic fuzzy set operations also include intersection, union and complement, and those operations are defined as

$$\text{Union: } A \cup B = \mu_A(x) \cup \mu_B(x) = \max(\mu_A(x), \mu_B(x)) \quad (4-5)$$

$$\text{Intersection: } A \cap B = \mu_A(x) \cap \mu_B(x) = \min(\mu_A(x), \mu_B(x)) \quad (4-6)$$

$$\text{Complement: } \bar{A} \rightarrow \mu_A(x) = 1 - \mu_A(x) \quad (4-7)$$

Where A and B are two fuzzy sets and x is an element in the universe of discourse X.[12]

4.2.2 Fuzzy Control Rules

Fuzzy control rule can be considered as the knowledge of an expert in any related field of application. The fuzzy rule is represented by a sequence of the form IF-THEN, The IF part of a rule is its antecedent and the THEN part is its consequent. Fuzzy input variables always appear in rule antecedents, rule consequent refers to one or more fuzzy output variables. Leading to algorithms describing what action or output should be taken in terms of the currently observed information, which includes both input and feedback if a closed-loop control system is applied.

The methods of deriving the rule base can be described as follows:

- i. Expert experience and control engineering knowledge
- ii. Based on operator's control actions
- iii. Based on fuzzy model of a process
- iv. Based on learning.

A fuzzy IF-THEN rule associates a condition described using linguistic variables and fuzzy sets to an output or a conclusion. For the sake of simplicity we consider a single rule of type IF x is A , THEN y is B which can be regarded as a fuzzy relation.

$$R: X \times Y \rightarrow [0, 1]$$

$$(x, y) \rightarrow R(x, y) \quad (4-8)$$

Where $R(x, y)$ is interpreted as the strength of relation between x and y . Viewed as a fuzzy set, with $\mu_R(x, y) = R(x, y)$, denoting the degree of membership in the fuzzy subset R , $\mu_R(x, y)$ is computed by means of a fuzzy implication. This IF-THEN rule is widely used by the fuzzy inference system to compute the degree to which the input data matches the condition of a rule.

4.2.3 Fuzzy inference

The conclusion or control output derived from the combination of input, output membership functions and fuzzy rules is still a vague or fuzzy element, and this process is called fuzzy inference. The fuzzy inference system is known by a number of names, such as fuzzy-rule-based system, fuzzy expert system, fuzzy model, fuzzy associative memory, fuzzy logic controller, and simply fuzzy system.[13]

There are many methods to perform fuzzy inference as follows:

- Max-Min.
- Max-Algebraic Product (or Max-Dot).
- Max-Drastic Product.
- Max-bounded Product.
- Max-bounded sum.
- Max-algebraic sum.
- Max-Max.
- Min-Max.

4.2.3.1 Max-Min Method (Mamdani)

This method uses the minimum operation RC as a fuzzy implication and the max-min operator for the composition. Suppose a rule base is given in the following form:

R_i : if u is A_i and v is B_i then w is C_i , $i = 1, 2 \dots n$

For $u \in U$, $v \in V$, and $w \in W$.

Then, $R_i = (A_i \text{ and } B_i) \rightarrow C_i$ is defined by

$$\mu_{R_i} = \mu_{(A_i \text{ and } B_i \rightarrow C_i)}(u, v, w).$$

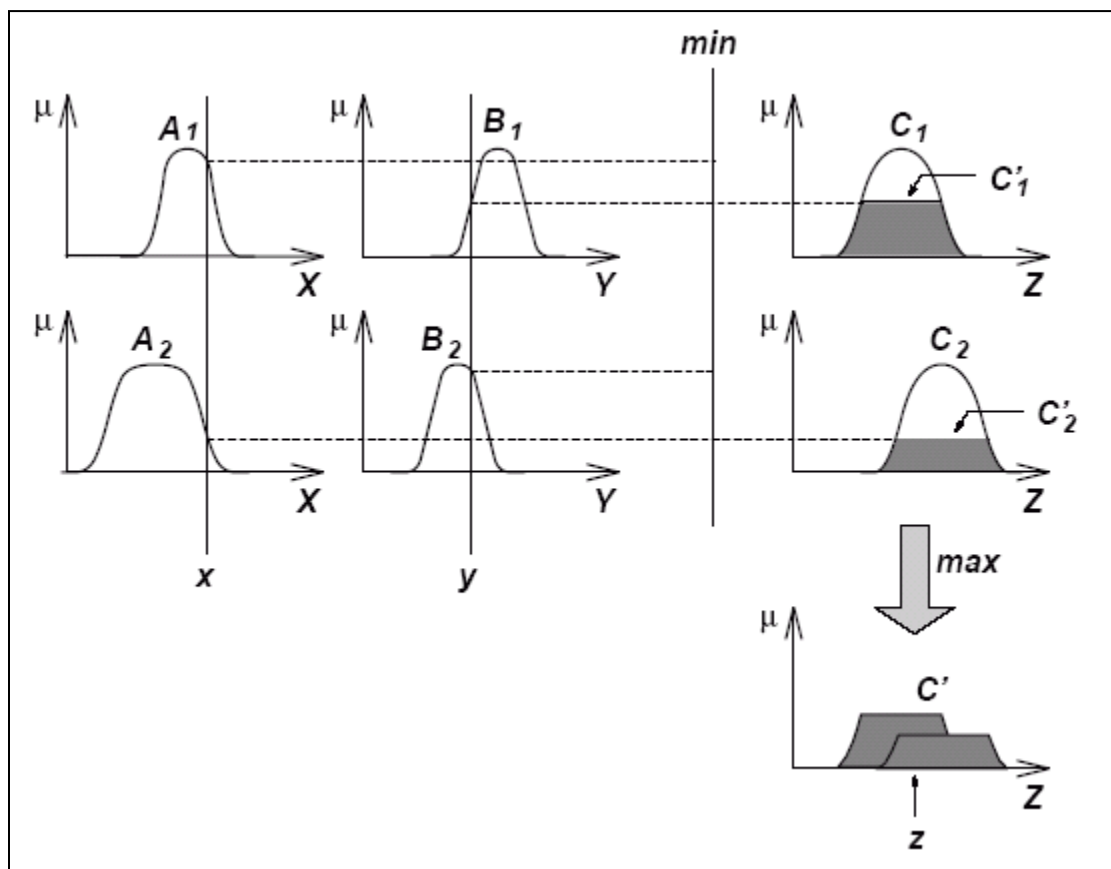


Figure 04-2: Max-Min Mamdani Method

4.2.4 Defuzzification

To make that conclusion or fuzzy output available to real applications, a defuzzification process is needed. The defuzzification process is meant to convert the fuzzy output back to the crisp or classical output to the control objective. Remember, the fuzzy conclusion or output is still a linguistic variable, and this linguistic variable needs to be converted to the crisp variable via the defuzzification process. The defuzzification methods:

- Max membership method.
- Center of gravity method.
- Weight average method.
- Mean-max membership method.

4.2.4.1 Max membership method

This method is limited to peaked output functions. This method is given by the algebraic expression:

$$\mu_z(z^*) \geq \mu_z(z) \quad \text{For all } z \in Z \quad (4-9)$$

4.2.4.2 Centre of gravity method

This procedure is the most prevalent and physically appealing of all the defuzzification methods. It is given by the algebraic expression:

$$z^* = \frac{\sum \mu_z(z) \cdot z}{\sum \mu_z(z)} \quad (4-10)$$

4.2.4.3 Weight average method

This method is only valid for symmetrical output membership functions. The weight average method is formed by weighting each membership function in the output by its respective maximum membership value. It is given by the algebraic expression:

$$z^* = \frac{\sum \mu_z(\bar{z}) \cdot \bar{z}}{\sum \mu_z(\bar{z})} \quad (4-11)$$

4.2.4.4 Mean-max membership method

This method is closely related to the first method, except that the locations of the maximum membership can be non-unique.[14] This method is given by the expression:

$$z^* = \frac{a+b}{2} \quad (4-12)$$

4.3 Summary

Fuzzy Logic provides a different way to approach a control or classification problem. This method focuses on what the system should do rather than trying to model how it works. One can concentrate on solving the problem rather than trying to model the system mathematically, if that is even possible. On the other hand the fuzzy approach requires a sufficient expert knowledge for the formulation of the rule base, the combination of the sets and the defuzzification. In General, the employment of fuzzy logic might be helpful, for very complex processes, when there is no simple mathematical model (e.g. Inversion problems), for highly nonlinear processes or if the processing of (linguistically formulated) expert knowledge is to be performed.

Chapter 5

Design of PID Controller using Fuzzy Logic

As we mentioned in previous chapters (two, three and four) PID controller is used in controlling the motion of an aircraft, the thesis focus on using PID controller by fuzzy logic in controlling the longitudinal motion of the aircraft (Pitch up & Pitch down). The chosen model of aircraft is the business star jet (see Appendix A). These data and coefficients are calculated assuming that the aircraft flying in straight and level flight at altitude 40,000ft, mach of 0.8 and 5° change in elevator angle. The longitudinal derivative and longitudinal control derivatives are both given in Appendix A.

The first step in the design is designing Conventional PID controller so as to control the longitudinal motion of the aircraft.

5.1 Designing Conventional PID Controller

The conventional PID controller is tuned by Ziegler Nichols. The value of K_p , K_i & K_d , and the aircraft equation of motion found based on business star jet aircraft model.

The characteristic equation $\Delta(s)$ factorizes into two pairs complex roots:

$$\Delta(s) = (s^2 + 0.0067s + 0.00433)(s^2 + 0.065s + 3.6481) = 0 \quad (5-1)$$

The first pair of complex roots describes the long period mode with characteristics: damping ratio $\zeta_p=0.05$ and un-damped natural frequency $\omega_p=0.0658$ rad/sec. The second pair describes the short period mode with characteristics: damping ratio $\zeta_s=0.02$ and un-damped natural frequency $\omega_s=1.91$ rad/sec.

5.1.1 Design for short period

The aircraft and servo motor function and value of proportional gain K_p , derivative gain K_d , and integral gain K_i are given from model as:

$$G_p = \frac{-0.3709s - 44.38}{s^3 + 9.46s^2 + 8.727s + 32.47} \quad (5-2)$$

Type of Controller	K_p	K_i	K_d
PID	-0.4626	0.002313	0.2313

Table 5.1 : Values of K_p and the initial value of K_i and K_d

Table (5.1) gives the value of K_p , K_i , and K_d which are calculated by using Ziegler-Nichols methods.

The response of the system in short period is shown in figure (5.1).

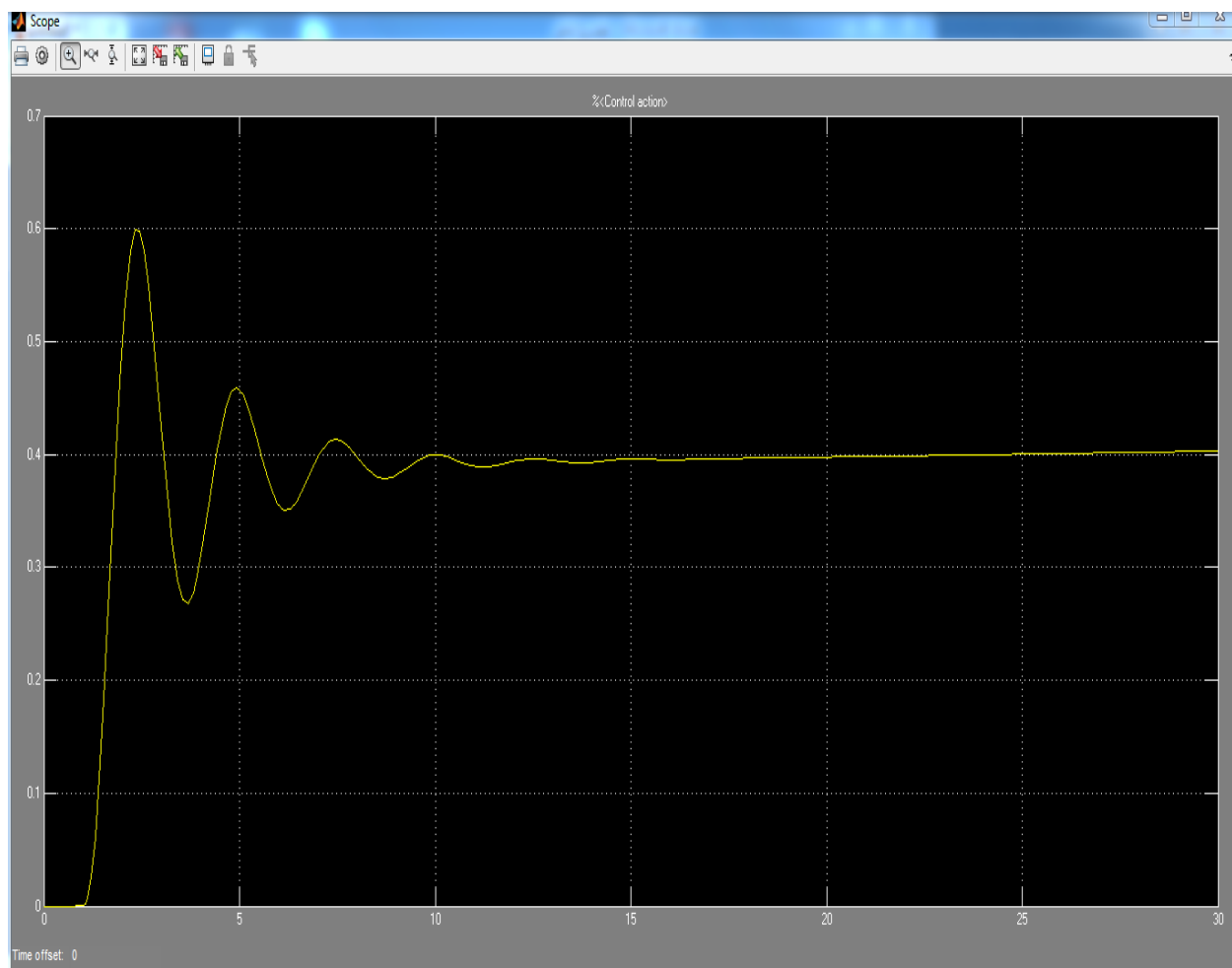


Figure 5.1: Short period Response.

The simulink block diagram is shown in figure (5.2)

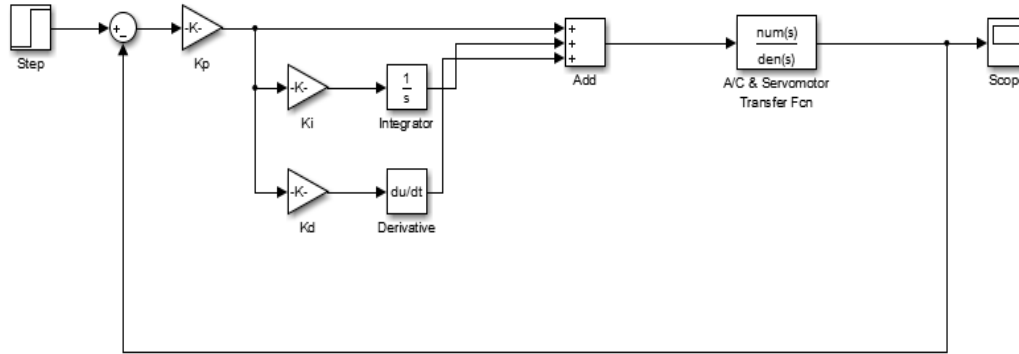


Figure 5.2: Block Diagram of Conventional PID Controller

5.2 Design of Self-Tuning Fuzzy PID Controller

The first step in designing Fuzzy PID controller is configuring the Fuzzy Inference System (FIS) so as it produce linear control surface from input E (error) and CE (error change) to the output K_p , K_i , and K_d (Proportional, integral and derivative gains). The FIS settings summarized below are based on design choices described in:

- Use Mamdani style fuzzy inference system.
- Use Algebraic product for AND connective.
- The ranges for input e is normalized to [-0.4 0.4], and ce is normalized to [-0.1 0.1].
- The input sets are triangle and cross neighbor sets at membership value of 0.
- The outputs ranges are [0 5], [0 0.1] and [0 0.05] for K_p , K_d and K_i respectively.
- Use trapezoidal sets for all outputs.
- Use minimum for implication method.
- Use maximum for aggregation method.
- Use the center of gravity method (COG) as defuzzification method.

5.2.1 Design for short period

The block diagram in figure (5.3) shows the design of the circuit in the short period, In self tuning fuzzy PID controller, the rules are designed based on characteristics of aircraft pitch control and properties of the PID controller. The parameters of K_p , K_i and K_d must be calculated from conventional PID controller designed previously in table (5.1).

The membership functions of the inputs fuzzy sets. The fuzzy sets for each input variables consisting of seven linguistic variables:

$$e = \{NB, NM, NS, ZE, PS, PM, PB\}$$

$$\Delta e = \{NB, NM, NS, ZE, PS, PM, PB\}$$

The outputs K_p , K_i and K_d linguistic variables are assigned as:

$$K_p = \{N, Z, P\}, K_i = \{N, Z, P\}, K_d = \{N, Z, P\}.$$

The Rule matrix of the fuzzy inference system shown in table (5.2).

	E	NB	NM	NS	ZE	PS	PM	PB
Δe	K_p K_d K_i							
NB		P N P	Z P Z	N P N	N N N	N P N	Z P Z	P N P
NS		P N P	P Z Z	Z P Z	N P N	Z P Z	P Z Z	P N P
NM		P N P	P N P	Z Z Z	N P N	Z Z Z	P N P	P N P
ZE		P N P	P N P	P N P	Z Z Z	P N P	P N P	P N P
PS		P N P	P N P	Z Z Z	N P N	Z Z Z	P N P	P N P
PM		P N P	P Z Z	Z P Z	N P N	Z P Z	P Z Z	P N P
PB		P N P	Z P Z	N P N	N P N	P N P	Z P Z	P N P

Table 5.2: Rule Matrix of Self-Tuning Fuzzy PID Controller

A unit step command is required in order for pitch angle to follow the reference value. The scaling factors, K_1 and K_2 are chosen to achieve satisfactory set of time domain parameters. The parameters value of K_p , K_i and K_d are tuned by using signals from fuzzy logic block based on the change of error between reference signals and output signals.

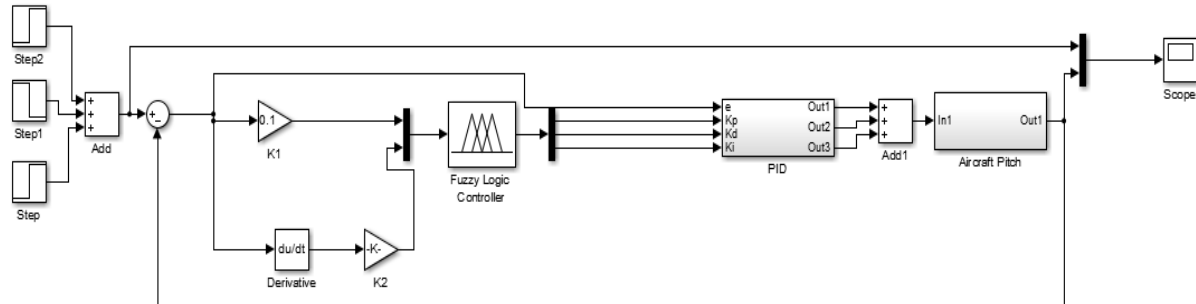


Figure 5.3: Block Diagram of Self-Tuning Fuzzy PID Controller

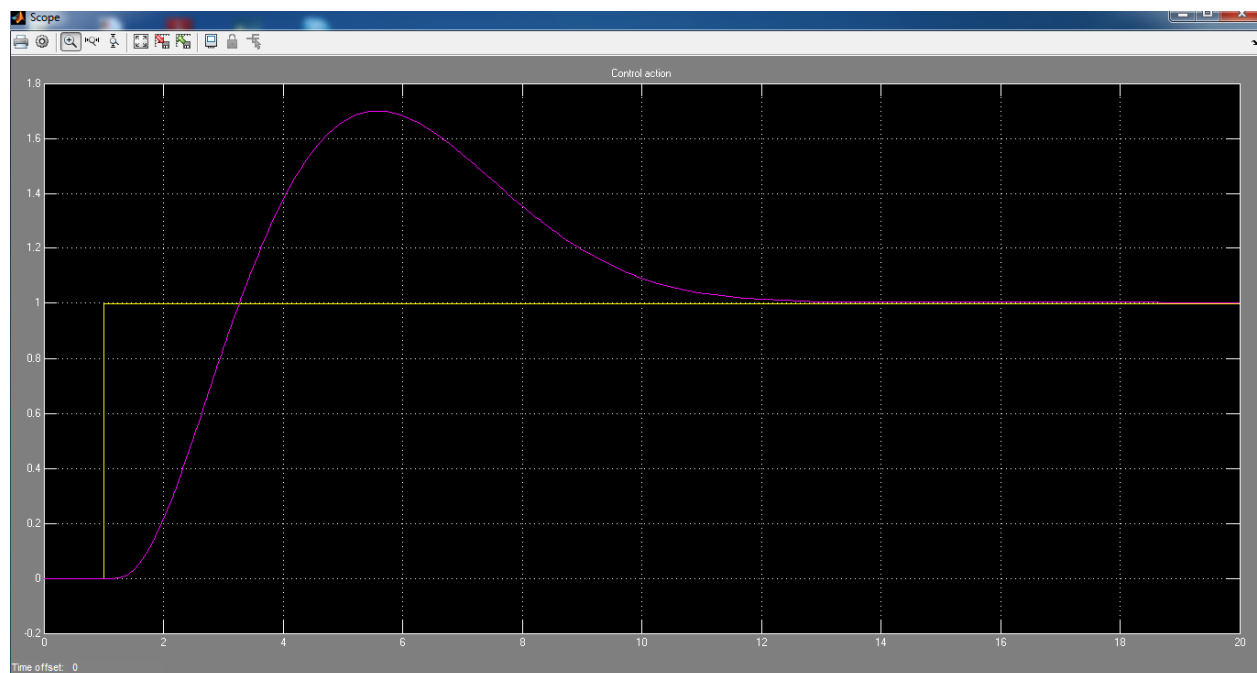


Figure 5.4: Response of Self-Tuning Fuzzy PID controller

Type of controller	Settling time	Percentage Overshoot	Steady-state error
Conventional PID	24s	33.3%	0.683
Self-Tuning Fuzzy PID	13.5s	40.1%	0

Table 5.3: Summary of Performance Characteristics of Conventional PID and Self-Tuning Fuzzy PID

5.3 Discussion

The results were showing in figures (5.1) and (5.4). The two figures showing that the response of Self-Tuning Fuzzy PID controller is better in settling time and steady state error but the percentage overshoot is increased because the using of Ziegler-Nichols method in tuning the parameters in the conventional PID. Therefore, a better solution to this problem is to use the discrete PID controller, or use another method in tuning the parameters of the conventional PID controller.

Chapter 6

Conclusion and Recommendation

6.1 Conclusion

The main goal of this study is to design a Self-Tuning fuzzy PID controller make a comparison between the conventional PID design and the fuzzy PID design. This design is eliminate at longitudinal autopilot system for an executive business jet-star aircraft for the short period of motion. From the discussion above, it is found that the response of Self-Tuning Fuzzy PID controller is better in settling time and steady-state error than the conventional PID controller, but the percentage overshoot is big than the conventional because of the use of Ziegler-Nichols for tuning the parameters. The solution can use any other tuning methods for the parameters of the PID controller.

6.2 Recommendation

This research deals with design and implementation of PID Fuzzy controller for a longitudinal Autopilot for Transport Aircraft. As a mid term work, we recommend to study the same design for the long period of motion for the same aircraft model. Also, as a long term work, the full design and analysis of a neuro- fuzzy PID controller will be develop for the longitudinal autopilot.

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Appendix A

Data and Coefficients of Business Jet-Star Aircraft

Table A1: Data for a business jet-star aircraft.

Parameter	Notation	Value
Mach number	Ma	0.8
Dihedral angle	Γ	1.4
Gravity	G	32.2
Atmospheric pressure	P_{atm}	393.1
Atmospheric temp.	T_{atm}	320
Reynolds number	R	1545
Total pressure	P	257.882
Total temp.	T	283.6879
Control force per g	Q	115.531
Aircrafts' velocity	u_o	626.67

Table A2: Center of gravity and reference geometry.

Coefficient	value	Coefficient	Value
m	1186.3354	I_x	118773
S	542.5	I_y	135869
b	53.75	I_z	243504
$\bar{c}$	10.93	I_{xz}	5061

Table A3: Coefficients of flight for M = 0.8 and altitude 40.000

Coefficient	Value	Coefficient	Value
C_L	0.4	$C_{m\delta e}$	-0.88
C_D	0.04	C_{yb}	-0.75
C_{La}	6.5	C_{pb}	-0.06
C_{Da}	0.6	C_{nb}	-0.13
C_{ma}	-0.72	C_{lp}	-0.42
C_{Lad}	0	C_{np}	-0.756
C_{mad}	-0.4	C_{lr}	0.04
C_{Lq}	0	C_{nr}	-0.16
C_{mq}	-0.92	C_{lda}	0.06
C_{LM}	0	C_{nda}	-0.06
C_{DM}	-0.6	C_{ydr}	0.16
C_{mM}	-0.6	C_{ldr}	0.029
$C_{L\delta e}$	0.44	C_{ndr}	-0.057

Table A4: Longitudinal stability and control derivatives coefficients.

Coefficient	Value
$C_{x\delta e}$	0
C_{Lo}	0.61
$X_{\delta e}$	0
$M_{\delta e}$	-602838.68
$Z_{\delta e}$	-27577.25

Table A5: Longitudinal derivatives.

X_u	-8
X_w	60
Z_u	-100
Z_w	-50
$Z_{\dot{w}}$	0
M_q	-5496.14
M_w	-787.1
$M_{\dot{w}}$	3.8
M_u	655.89