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Performance Analysis of Control Techniques for Roll Movement of Aircraft

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ABSTRACT:-This paper presents the applications of intelligent control techniques implemented for roll angle control of aircraft system. The aircraft roll control system is designed with rate gyro and rate integrating gyro**.** The controllers are designed on the basis of dynamic modeling of the aircraft system for roll angle control. The modeling begins with a derivation of suitable mathematical model to describe the lateral dynamic motion of the aircraft. The roll angle of aircraft is controlled by ailerons on either side of aircraft. The simulation model for aircraft roll angle control is implemented using various controllers as cited below. A comparative assessment between PID, ANN, Fuzzy, Fuzzy-PID and ANFIS controllers based on time response specifications has been investigated and analyzed using MATLAB Simulink©.

Keywords- ANN, Roll Angle, Ailerons, Gyro, Rate-Integrating Gyro, FLC, ANFIS.

1. INTRODUCTION

Generally aircraft contains three rotational movements: pitch, yaw and roll. The roll movement of aircraft is controlled by ailerons on either side of the airplane. The two ailerons are interconnected to each other and both move in inverse heading to each other. The ailerons are utilized to bank the aircraft. The saving money makes an unequal side power segment of extensive wing lift powers which causes the aircraft flight path to curve. Therefore when pilot applies right push power on the stick, as the aileron on the conservative is avoided upwards, the aileron on the left wing is diverted downwards. As an after effect of this, lift on the left wing is expaned, while lift on the conservative is diminished. So the air ship performs moving movement to the all right from the back of aircraft.

A few recent techniques implemented for roll control of aircraft are listed below, with every methodology having its own merits and demerits.

1. To begin with control technique utilized for Aircraft move control is utilizing Fuzzy rationale controller. In this paper Fuzzy tenets were produced to decide the fitting control surface avoidances to accomplish the sought move rate while guaranteeing that wing burdens are inside safe limits. The tweak of the damping element is as indicated by the separation of the framework state from the objective state. This damping balance system permits full use of the vehicle's increasing speed ability and brought about a change of the reaction time by an element of two. The resultant fuzzy controller charges six surface avoidances to control the move rate and four torsion minutes [1].

2. The second technique is Adaptive control framework for detachment of aircraft movement on roll and sideslip. In this paper the answer for a decoupled movement of a aircraft is acquired in the class of non-seeking versatile control frameworks with a reference model. The new calculations created in this paper accomplish a decoupled movement with attractive element exactness even in the states of high non-stationary of parameters [2].

3. The third strategy utilized is for air ship move control depends on LQR and Fuzzy rationale controller. In this paper the Linear Quadratic Controller (LQR) and Fuzzy Logic Controller (FLC) are produced for controlling the move point of an aircraft framework [3].

4. The fourth strategy utilized for controlling aircraft move control depends on Fuzzy-PID controller. In this work a Fuzzy-PID controller has been outlined and executed in ASIC with a specific end goal to control move movement. Initial step is to distinguish an appropriate controller which is trailed by displaying of the controller and finally by the equipment usage. Programming reenactments demonstrate that the execution of move control framework has enhanced fundamentally utilizing a Fuzzy- PID controller contrasted with a routine PID controller. The working recurrence of the configuration in FPGA is 29.83MHz while in ASIC it is 56.05MHz [4].

Although some of the intelligent controllers already been implemented, yet in the present paper we have developed our own fuzzy model as well as Fuzzy-PID controller with fuzzy compensation technique. Other control systems such as ANFIS, neural network are the need of great importance, since they depend on learning, memory and thinking capacity. These are learning based controllers with thinking as opposed to exclusively depending on a scientific model. Among these sharp methods, it shows up those considering fuzzy basis perform better similarly as reduced exploratory model multifaceted design and speedy consistent operation furthermore being least affected by parameters shakiness or adjustment to non-basic disappointment when diverged from various techniques.

2. METHADOLOGY

In control engineering, a controlled system is primarily characterized by its dynamic behavior to solve a control task. The step response of controlled system is used to reflect this dynamic behavior. The step response reveals how controlled variable reacts to a change in the manipulated variable. This is determined by measuring the controlled variable after a step change in the manipulated variable. Transient characterstics of the step response such as rise time, settling time, steady state error, peak amplitude, overshoot can be used to evaluate the controller performance.

2.1 PID Controller

A proportional–integral–derivative controller (PID controller) is a nonexclusive control circle criticism component (controller) broadly utilized as a part of mechanical control frameworks. A PID controller endeavors to remedy the blunder between a deliberate procedure variable and a fancied set-point by ascertaining and after that yielding a restorative activity that can alter the procedure as needs be.

The PID controller estimation (calculation) includes three separate parameters; the Proportional, the Integral and Derivative qualities. The Proportional worth decides the response to the present mistake, the Integral quality decides the response in light of the aggregate of late blunders, and the Derivative worth decides the response taking into account the rate at which the blunder has been evolving. The weighted entirety of these three activities is utilized to modify the procedure by means of a control component, for example, the position of a control valve or the force supply of a warming component.

By "tuning" the three constants in the PID controller calculation, the controller can give control activity intended to particular procedure prerequisites. The reaction of the controller can be depicted as far as the responsiveness of the controller to a mistake, the extent to which the controller overshoots the set-point and the level of framework wavering. Note that the utilization of the PID calculation for control does not ensure ideal control of the framework or framework security.

A few applications may require utilizing one and only or two modes to give the proper framework control. This is accomplished by setting the increase of undesired control yields to zero. A PID controller will be known as a PI, PD, P or I controller without the individual control activities. PI controllers are especially basic, since subordinate activity is exceptionally delicate to estimation clamor, and the nonappearance of a basic quality may keep the framework from achieving its objective worth because of the control activity.

Numerically a PID controller can be depicted as:

$$u(n) = k_p e(t) + k_i \int_0^t e_t \; d(t) + k_d \frac{d}{dt} e(t) \quad (1)$$

Where t is the control signal which will be sent to the process. K_p, $K_i$and K_d represents proportional, integral and derivative gains respectively.

The PID controller tuning method adopted for the given process is using PID control algorithm tuning based on compensator formula in MATLAB.

2.2 Fuzzy-Logic Controller

An imperative issue in self-sufficient route of any framework is the need to adapt to huge measure of instability that is innate of common habitats. Fuzzy rationale has highlights that makes it well-suited in such cases. Dissimilar to traditional rationale, fuzzy rationale is help to be tolerant to imprecision, instability and fractional truth. This makes it simpler to execute fluff rationale controllers to non-direct models than other customary methods.

Fuzzy rationale is likewise adaptable as in extra usefulness can be forced on the framework without building the framework sans preparation [12]. Higher static exactness and speedier element reaction can be accomplished by consolidating the fuzzy rationale controller and PID controller. It is in this way trusted a superior control framework to exploit PID control and fuzzy control can be accomplished by sufficiently coordinating these two techniques [13]. The PID parameters are tuned by utilizing fuzzy interface which gives a non direct mapping from the blunder and inference of mistake to the PID controller.

Fuzzy logic expressed operational laws in linguistics terms instead of mathematical equations. Many systems are too complex to model accurately, even with complex mathematical equations; therefore traditional methods become infeasible in these systems. However, fuzzy logic's linguistic terms provide a feasible method for defining the operational characteristics of such systems. Fuzzy logic controller can be considered as a special class of symbolic controller. The configuration of fuzzy logic controller block diagram is shown in Fig.2.

The fuzzy logic controller has three main components

1. Fuzzification
2. Fuzzy inference
3. Defuzzification

2.2.1 Fuzzification

Various measured fresh inputs must be initially mapped into fuzzy enrollment capacities. This procedure is called fuzzification. It then plays out a scale mapping that exchanges the scope of estimations of information variables into comparing universe of talk. At that point, it plays out the capacity of fuzzification that believers info information into reasonable etymological qualities which might be seen as names of fuzzy sets.

Fuzzy rationale etymological terms are regularly communicated as sensible ramifications, for example, if-then standards. These guidelines characterize a scope of qualities known as fuzzy enrollment capacities. Fuzzy participation capacities might be as a triangular, a trapezoidal, a chime molded or any another suitable from.

2.2.2 Fuzzy inference

Fuzzy derivation is the procedure of detailing the mapping from an offered contribution to a yield utilizing fuzzy rationale. The mapping then gives a premise from which choices can be made, or designs perceived. There are two sorts of fuzzy surmising frameworks that can be executed in the Fuzzy Logic Toolbox: Mamdani-sort and Sugeno-sort. These two sorts of surmising frameworks shift to some degree in the way yields are resolved. Due to its multidisciplinary nature, fuzzy derivation frameworks are connected with various names, for example, fuzzy tenet based frameworks, fuzzy master frameworks, fuzzy demonstrating, fuzzy affiliated memory, fuzzy rationale controllers, and just (and equivocally) fuzzy.

Mamdani's fuzzy derivation technique is the most normally seen fuzzy philosophy. Mamdani's technique is among the main control frameworks manufactured utilizing fuzzy set hypothesis. It was proposed in 1975 by Ebrahim Mamdani as an endeavor to control a steam motor and kettle mix by integrating an arrangement of etymological control rules got from experienced human administrators. Mamdani's exertion depended on Lotfi Zadeh's 1973 paper on fuzzy calculations for complex frameworks and choice procedures. The second period of the fuzzy rationale controller is its fuzzy deduction where the information base and basic leadership rationale dwell .The tenet base and information base frame the learning base. The information base contains the depiction of the information and yield variables. The basic leadership rationale assesses the control rules. The control-standard base can be produced to relate the yield activity of the controller to the acquired inputs.

2.2.3 Defuzzification

The yield of the derivation instrument is fuzzy yield variables. The fuzzy rationale controller must change over its inner fuzzy yield variables into fresh values so that the real framework can utilize these variables. This transformation is called defuzzification. One may play out this operation in a few ways. The usually utilized control defuzzification methodologies are:

(a).The max standard technique (MAX)

The maximum standard delivers the time when the enrollment capacity of fuzzy control activity achieves a most extreme quality.

(b) The height technique

The centroid of every enrollment capacity for every guideline is initially assessed. The last yield is then computed as the normal of the individual centroids, weighted by their statures.

(c) .The centroid strategy or focal point of zone technique (COA)

The broadly utilized centroid system creates the focal point of gravity of territory limited by the Membership capacity bend [5].

The membership functions designed for roll control of aircraft are shown below in Fig.5. considering two inputs for fuzzy one as roll rate error and another as derivative of roll rate error. The range of these input membership functions are displayed in the figure. And the control action of the fuzzy is single output for roll control. We have considered 5 MF's each for two input variable and 9 MF's for output variable.

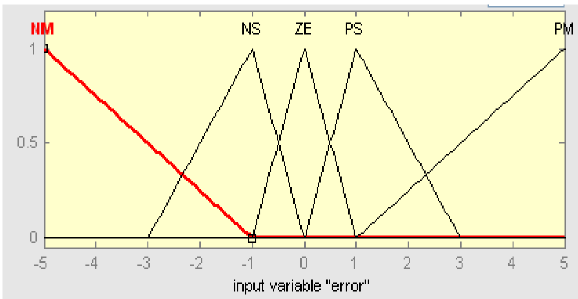

Fig.2.2(a) Membership functions for input (error)

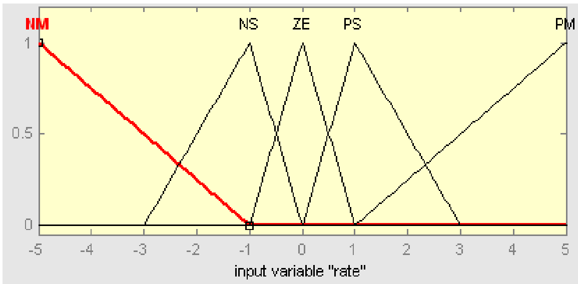

Fig.2.2(b) Membership functions for input (rate)

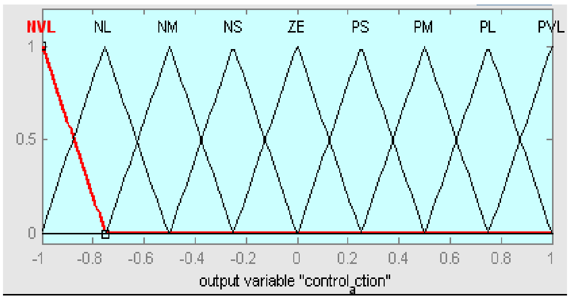

Fig.2.2(c) Membership functions for output (control action)

Table 2.2.1. Rules for FLC

e / de	NM	NS	ZE	PS	PM
NM	NVL	NL	NM	NS	ZE
NS	NL	NM	NS	ZE	PS
ZE	NM	NS	ZE	PS	PM
PS	NS	ZE	PS	PM	PL
PM	ZE	PS	PM	PL	PVL

2.3 PID CONTROLLER WITH FUZZY COMPENSATION

PID controllers generally do not work very well for nonlinear systems, higher order and time-delayed linear systems, and particularly complex and vague systems that have no precise mathematical models. To overcome these difficulties, various type of modified conventional PID controllers such auto tuning and adaptive PID controllers.

Fig.8 shows the structure of Fuzzy-PID controller which has been developed for the aircraft pitch and roll control model. This model of Fuzzy-PID controller developed here is using fuzzy compensation technique. The purpose of compensation is to achieve the desired performance of the system. By using compensation we feed the output of the process back to FLC as input, till the process becomes stable.

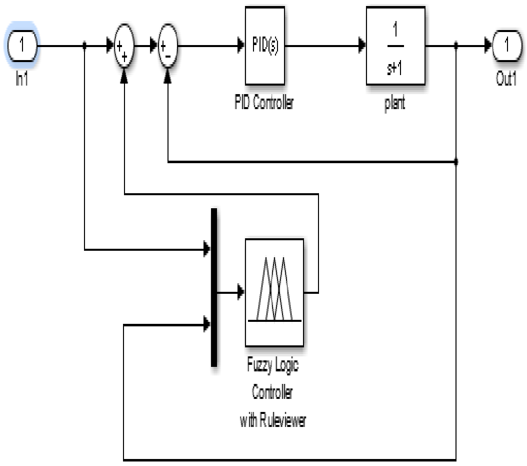

Fig. 2.3.1 Fuzzy-PID controller with fuzzy compensation.

2.4 Neural Network

Simulated Neural Network is a control instrument utilized as a part of control hypothesis and is extremely successful in flight control framework planning. The ANN technique is roused by natural neural systems which are utilized to gauge or surmised capacities that can rely on upon an extensive number of inputs and are by and large obscure. Simulated neural systems are by and large displayed as frameworks of interconnected "neurons" which trade messages between each other. The associations have numeric weights that can be tuned in view of experience, making neural nets versatile to inputs and fit for learning. The neural system created in this paper is by utilizing bolster forward neural system.

A feedforward neural system is a simulated neural system where associations between the units don't frame a cycle. This is not quite the same as intermittent neural systems. In this system, the data moves in one and only bearing, forward, from the information hubs, through the shrouded hubs (assuming any) and to the yield hubs. There are no cycles or circles in the system. ANN preparing calculation.

Preparing in an ANN implies that the system alters its own weighted associations in a way that the consequences of the system yield get to be like the craved yield. Other than preparing, speculation is of principal significance in an ANN. That is, the system ought to have the capacity to create suitable yields with respect to the untrained contribution (out-of-test). The ANN's reaction to new info ought to be like the framework's reaction [3]. In the accompanying paper we supply two information inputs and one yield taken from FLC. These information are moved to workspace in Matlab and taking after ANN calculation is being executed, whose code is given underneath.

At the point when the accompanying system is executed the neural system begins preparing the information and executes a solitary ANN piece. This neural system square is supplanted in the pitch control simulink obstruct with alternate controllers and the relating results are being noted. The accompanying figure demonstrates the simulink piece outline for flying machine pitch control with ANN [18].

In the present work we are considering an elementary feed forward architecture of one neurons receiving two inputs as shown in fig. Its output and input vector are, respectively

$$o = [o_1\, o_{2 \dots} o_m].^t \qquad (1)$$

$$x = [x_1\, x_2 \dots x_n].^t \qquad (2)$$

Weight w_{ij} connects the i'th neuron with the j'th input. The double subscript convention used for weights is such that the first and second subscript denote the index of the destination and source nodes, respectively. The activation value for the i'th neuron as

$$net_i = \sum_{j=1}^{n} w_{ij}\, x_{ij}, \quad \text{for i = 1,2,...,m} \qquad (3)$$

The following nonlinear transformation eq. (4) involving the activation function $f(net_i)$, for i= 1,2,..., m, completes the processing of x. The transformation, performed by each of the m neurons in the network, is a strongly nonlinear mapping expressed as

$$o_i = f(w_i^t x), \quad \text{for i= 1,2,..., m} \qquad (4)$$

Where weight vector w_i contains weights leading towards the i'th output node and is defined as follows

$$w_i \triangleq [w_{i1}\, w_{i2} \dots w_{in}] \qquad (5)$$

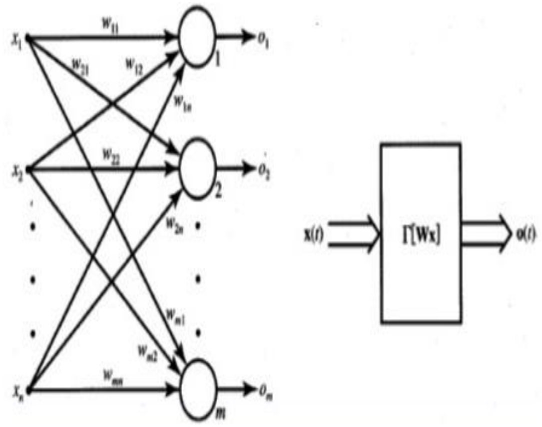

Fig.2.4.1 Single layer feed forward network

Introducing the nonlinear matrix operator Γ. The mapping of input space x to output space o implemented by the network can be expressed as follows

O=Γ$|Wx|$ (6)

Where W is the weight matrix, also called the connection matrix:

when the accompanying system is executed the neural system begins preparing the information and executes a solitary ANN piece. This neural system square is supplanted in the pitch control simulink obstruct with alternate controllers and the relating results are being noted. The accompanying figure demonstrates the simulink piece outline for flying machine pitch control with ANN [6].

2.5 ANFIS

A neuro-fuzzy (ANFIS) framework is a mix of neural system and fuzzy frameworks in a manner that neural system is utilized to decide the parameters of fuzzy framework. ANFIS to a great extent expels the prerequisite for manual enhancement of the fuzzy framework parameters. A neural system is utilized to consequently tune the framework parameters, for instance the participation capacities limits, prompting enhanced execution without administrator creation.

The ANFIS with the learning ability of neural system and with the benefits of the standard base fuzzy framework can enhance the execution altogether and can give an instrument to consolidate past perceptions into the arrangement procedure. In neural system the preparation basically fabricates the framework. Nonetheless, utilizing an ANFIS plan, the framework is worked by fuzzy rationale definitions and is then refined utilizing neural system preparing calculations.

The possibility of ANFIS is to discover the parameters of a fuzzy by method for taking in techniques got from neural system. A typical approach to apply a learning calculation to a fuzzy framework is to speak to it in an extraordinary neural system like design. At that point a learning calculation, for example, bolster forward is utilized to prepare the framework. In any case, neural system learning calculations are generally inclination plunge strategies. This can't be connected straightforwardly to a fuzzy framework, in light of the fact that the capacities used to understand the induction procedure are typically not differentiable. With a specific end goal to understand the framework, we have to supplant the capacities utilized as a part of the fuzzy framework (like min and max) by differentiable capacities or don't utilize a slope based neural learning calculation however a more qualified technique.

Present day ANFIS are frequently spoken to as multilayer food forward neural system. ANFIS is a fuzzy framework that is prepared by a learning calculation (generally) got from neural system hypothesis. The (heuristic) learning strategy works on nearby data, and causes just neighborhood change in the comprehension fuzzy framework. The learning procedure is not information based, but rather information driven. Plus, ANFIS can simply be translated as an arrangement of fuzzy principles. It is conceivable both to make the framework out of preparing information structure scratch, and to instate it from earlier learning as fuzzy tenets.

The learning procedure of an ANFIS takes the semantical properties of the underlying fuzzy system into account. This results in constraints on the possible modification of the system's parameters. The fuzzy rules encoded with the system represent vague samples, and can be viewed as vague prototypes of the training data.

Generally, an ANFIS should not be seen as a kind of (fuzzy) expert system, and it has nothing to do with fuzzy logic in the narrow sense. It can be viewed as a special kind of feed forward neural network. The units in this network uses t-norms or t-conorms instead of the activation functions normally used in neural network. Fuzzy sets are encoded as (fuzzy) connection weighs.

ANFIS Architecture

The ANFIS is a fuzzy-Sugeno model put in the structure of versatile framework to encourage learning and adjustment [33] appeared in Figure . Such structure makes the ANFIS displaying more efficient and less dependent on master learning. To display the ANFIS engineering, two fuzzy if-then guidelines in light of a first request Sugeno model are considered:

Rule 1: If (x is A1) and (y is B1) then (f1=p1x +q1y +r1)

Rule 2: If (x is A2) and (y is B2) then (f2= p2x + q2y + r2)

Where x and y are the inputs, Ai and Bi are the fuzzy sets, fi are the yields inside the fuzzy area indicated by the fuzzy principle, pi, qi and ri are the configuration parameters that are resolved amid the preparation procedure.

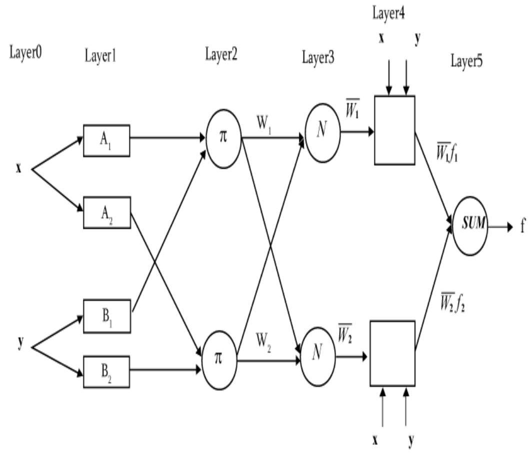

Fig.2.5.1 Basic structure of ANFIS

The node functions in the same layer are the same as described below:

Layer 1: all the node are adaptive nodes. The output of layer 1 are the fuzzy membership grade of the inputs, which are given by eq. (2.5..1) and (2.5.2)

O1i = μAi(x) i=1,2 (2.5.1)

O1i = μBi-2(y) i=3,4 (2.5.2)

Where , μAi(x), μBi-2(y) can adopt any fuzzy membership function. For example, if the Gaussian membership functions is employed, μAi(x) is given by (2.5.3)

$$\mu_{Ai}(x) = \frac{\exp(-0.5(\mathrm{x}-\mathrm{c_i})2}{6_i^2} \qquad (2.5.3)$$

Where ci and 6i are the parameters of the membership function, governing the Gaussian functions accordingly.

Layer 2: The nodes are fixed. They are labeled with ∏, indicating that they perform as a simple multiplier. The outputs of this layer can be represented by eq. (2.5.4)

O2,I = wi = μAi(x) μBi(y) i=1,2 (2.5.4)

Which are so called firing strengths of the rules.

Layer 3: In the layer, the nodes are also fixed nodes labeled by N, to indicate that they play a normalization role to the firing strengths from the previous layer. The output of this layer can be represented by eq. (2.5.5)

$$O_{3,I} = w_i = \frac{w_i}{w_1} - \frac{w_i}{w_2} \quad i=1,2 \qquad (2.5.5)$$

Which are so called normalized firing strengths.

Layer 4: In the fourth layer, the nodes are adaptive. The output of each node in this layer is simply the product of the normalized firing strength and a first order polynomial (for a first order Sugeno model).Thus, the output of this layer is given by eq. (2.5.6)

$$O_{4,i} = wi\, fi = wi(pix + qiy + ri) \quad i= 1,2 \qquad (2.5.6)$$

Layer 5: In the fifth layer, there is only single fixed node labeled with $\sum$. This node performs the summation of all incoming signals. Hence, the overall output of the model is given by eq. (2.5.7)

$$O_{5,i} = \frac{\sum i\, w_i f_i}{\sum i\, w_i} \quad i=1,2 \qquad (2.5.7)$$

It can be observed that there are two versatile layers in this ANFIS design, specifically the first and the fourth layers. The parameters of first layer which are identified with the info participation capacities are the alleged parameters. The parameters of fourth layer which are altered parameters are the purported subsequent parameters [7].

3. Mathematical modeling for Roll Control of aircraft

For modeling of aircraft roll control let us consider the control of single degree of flexibility moving methods of flying machine and efficiently controlled rockets. Such a mode emerges from the de-coupling of move from the contribute and yaw a straight estimate of the vehicle's rotational flow and is spoken to by the accompanying exchanges capacity between bank edge, Φ(s), and the aileron deflection angle, δ_a :

$$\frac{\Phi(s)}{\delta_{a(s)}} = \frac{C_{l_{\delta_a}}}{s(\frac{J}{qSb}s - \frac{b}{2v}C_{l_p}})} \qquad (3.1)$$

Where J is the moment of inertia about the roll axis, C_{l_p} is the stability derivative representing damping in roll, and $C_{l_{\delta_a}}$ is the stability derivatives representing the rolling moment due to aileron deflection angle. This plant has a first order time constant $T = -\frac{2vJ}{qSb^2 C_{l_p}}$ in addition to a pole at s=0. The aileron actuator can be assumed to be a linear, second-order transfer function with nonlinear saturation limits, $|\delta_a| \leq \delta_{max}$. Since the plant has a pole at origin, it can produce a desired step change in blank angle in a closed-loop, proportional feedback control system, such as the one approximately provided by a rate-integrating gyro [8].

GYROSCOPIC SENSOR

For mathematical modeling of gyroscope the first practical analog feedback device employed in a closed-loop flight control system is a ***gyroscope*** (also called ***gyro*** in short), where a spinning rotor mounted on a restrained ***gimbal*** could act as either a multiplier (gain) or an integrator of the error signal (an angular rate).

The dynamical equation for gimbal can be written as follows:

$$J\ddot{\theta}(t) + c\dot{\theta}(t) + k\theta(t) = -H_r\,\dot{\psi}(t) \qquad (3.2)$$

Where J is the moment of inertia of the gimbal and rotor assembly about the axis oy. Equation (2) has following equilibrium solution, $\theta(t) = \theta_e$. In the steady $(t \to \infty)$, obtained by letting $\theta = \dot{\theta} = 0$:

$$\theta_a = -\frac{H_r}{k}\dot{\psi} \qquad (3.3)$$

Which implies a gimbal angle proportional to the vehicle's rotation rate. Hence , the spinner is known as a rate gyro, as it can be adjusted to quantify a vehicle's consistent state rate about the information pivot. The time taken to achieve the consistent state for a given change in the vehicle's rate relies on the damping steady, c, and also the snippet of inertial, J, while the balance estimation of the gimbal point, Eq. (3), depends just upon the proportion of the rotor's precise energy, H_r with the spinning stiffness, k. By altering this later proportion, the rate gyro can be made increasingly (or less) delicate to the vehicle's rate. Then again, by conforming the damping consistent the gyro elements can be speeded up, or backed off, making it react rapidly (or gradually) to an adjustment in the vehicle's rate. If the restraining spring is removed from the rate gyro, the transfer function of the resulting mechanism (called ***rate-integrating***-or **displacement –gyro**) becomes

$$\frac{\theta(s)}{\psi(s)} = -\frac{H_r}{Js+C} \quad (3.4)$$

The plant and gyro sensors can be displayed utilizing the ceaseless framework siumlink hinders with proper exchange function. The demonstrating of the controller and actuator progression involving demeanor thrusters and an exchanging control law is through the nonlinear relationship, which can be effectively consolidated in a simulink model by the aggregate, no man's land, sign, and steady pick up pieces . Likewise, an irregular unsettling influence information, emerging out of a sunlight based radiation and gravity inclination torques, can be included by utilizing a background noise.

For mathematical modeling we consider a fighter aircraft with following specifications i.e., with wing span, $b = 14m$, platform area, $S = 56.5m^2$, moment of inertia about roll axis, $J = 34{,}700\,kg - m^2$, flying straight and level at constant speed, $v = 236.2\,m/s$ at standard altitude 12.195km where the dynamic pressure is $q = 8439.4\,N/m^2$, $C_{l_p} = -0.27/rad$, and $C_{l_{\delta_a}}$ = 0.045/rad. The airplane is equipped with aileron actuator with the following first order transfer function between the commanded aileron deflection angle, δ_{ac}(s), and the actual aileron deflection angle, δ_a:

$$\frac{\delta_a\,(s)}{\delta_{ac}(s)} = \frac{20}{s+20}$$

Structural limitations restrict the maximum aileron deflection at the given speed to $|\delta_a| \leq 10°$. A *roll autopilot* is designed with the rate-integrating gyro with following characterstics: $H_r = 10^4\,g - \frac{cm^2}{s}$, $J = 34\,g - cm^2, k = 3.03 \times 10^5\,g - cm^2/s^2$, and $c = 5000\,g - \frac{cm^2}{s}$. The simulation is carried out by simulink block diagram shown in fig.7. A modified roll autopilot for fighter aircraft by adding the rate gyro with scaling gain $K_D = 30.3$ in the feedback loop. The modified simulink block diagram is shown in Fig.8, with the simulated bank and aileron angle responses [8].

4. Matlab/Simulink model for air craft roll control

Fig 4(a) and 4(b) shows matlab/simulink model for aircraft roll control using rate-integrating gyro and rate and rate-integrating gyro. On the basis of these models other controllers are developed and tuned.

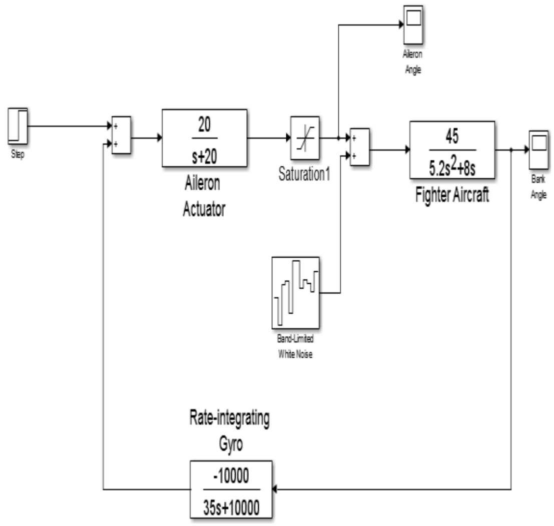

Fig. 4(a) Simulink block diagram for step response of roll autopilot for fighter airplane with a rate-integrating gyro.

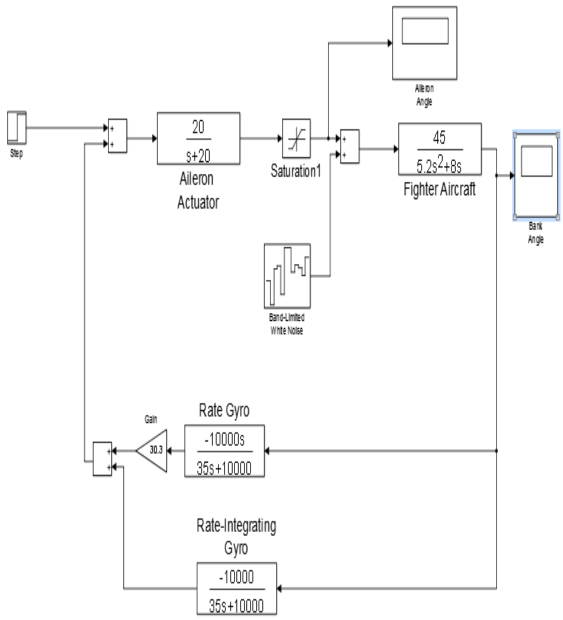

Fig. 4(b) Simulink block diagram for step response of roll autopilot with rate and rate-integrating gyro.

4.1 Aircraft Roll control using PID Controller.

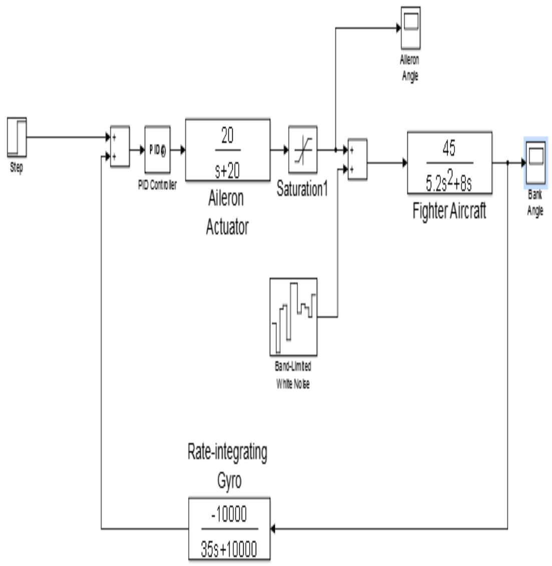

Fig.4.1 Simulink Block diagram for step response for roll autopilot for fighter aircraft with rate-integrating gyro using PID.

4.2 Aircraft Roll control using Fuzzy Logic Controller.

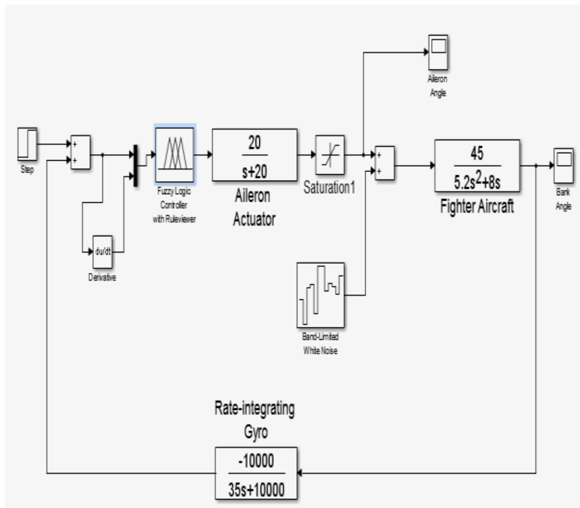

Fig.4.2 Simulink block diagram for step response of roll autopilot for fighter aircraft with rate integrating gyro using fuzzy logic controller

4.3 Aircraft Roll control using ARTIFICIAL NEURAL NETWORK (ANN)

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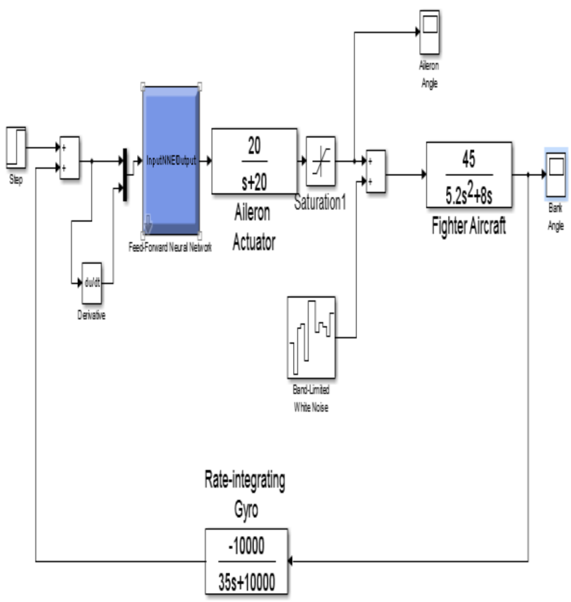

Fig.4.3 Simulink block diagram for step response of roll autopilot for fighter aircraft with rate integrating gyro using ANN.

4.4 Aircraft Roll control using ANFIS

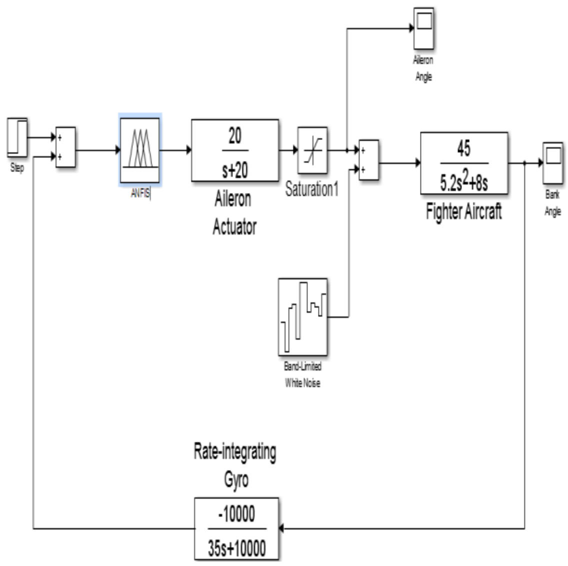

Fig.4.4 Simulink block diagram for step response of roll autopilot for fighter aircraft with rate integrating gyro using ANFIS

4.5 Aircraft Roll Control using Fuzzy-PID Controller

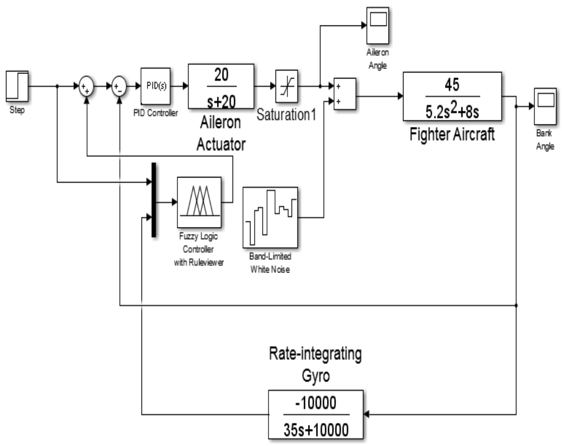

Fig.4.5 Simulink block diagram for step response of roll autopilot for fighter aircraft with rate integrating gyro using Fuzzy-PID

5. RESULTS AND DISCUSSIONS

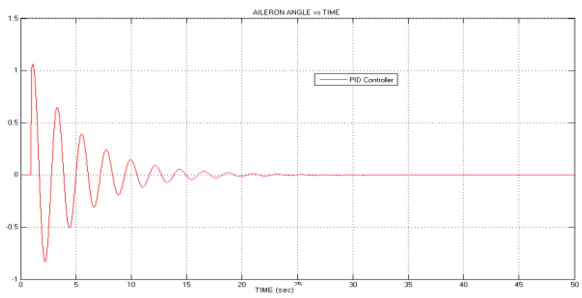

Fig.5.1(a) Step Output response of PID controller for fighter aircraft showing Aileron deflection angle response with roll-rate-integrating gyro.

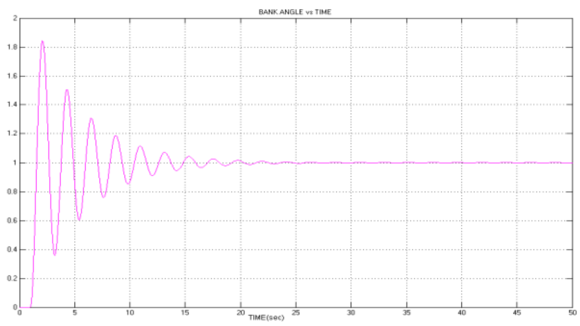

Fig.5.1(b) Step Output response of PID controller for fighter aircraft showing Bank deflection

angle response with roll-rate-integrating gyro.

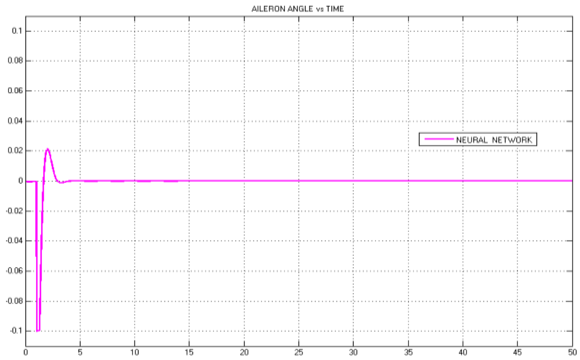

Fig.5.2(a) Step Output response of ANN controller for fighter aircraft showing Aileron deflection angle response with roll-rate-integrating gyro

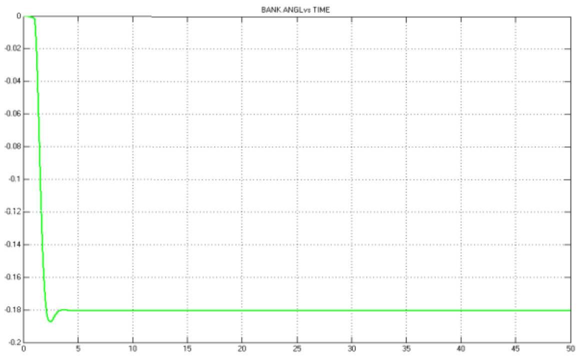

Fig.5.2(b) Step Output response of ANN controller for fighter aircraft showing Bank deflection angle response with roll-rate-integrating gyro

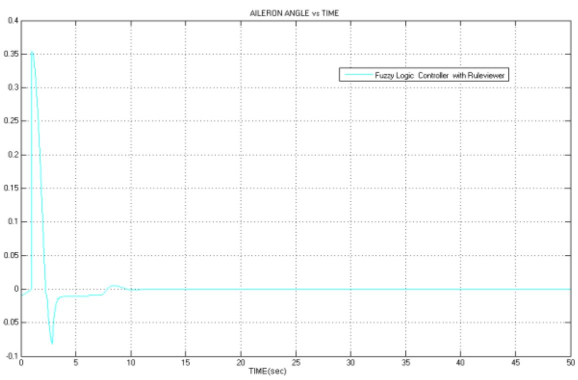

Fig.5.3(a) Step Output response of Fuzzy controller for fighter aircraft showing Aileron deflection angle response with roll-rate-integrating gyro.

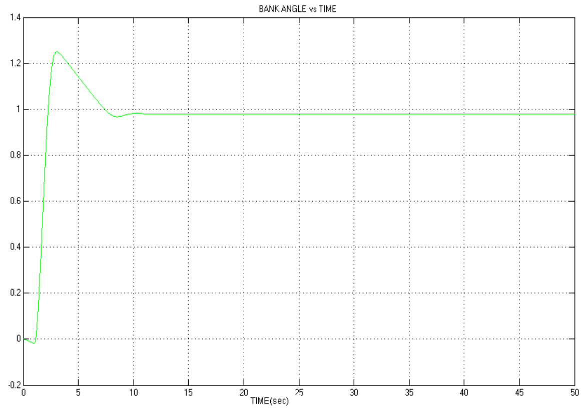

Fig.5.3(b) Step Output response of Fuzzy controller for fighter aircraft showing Bank deflection angle response with roll-rate-integrating gyro

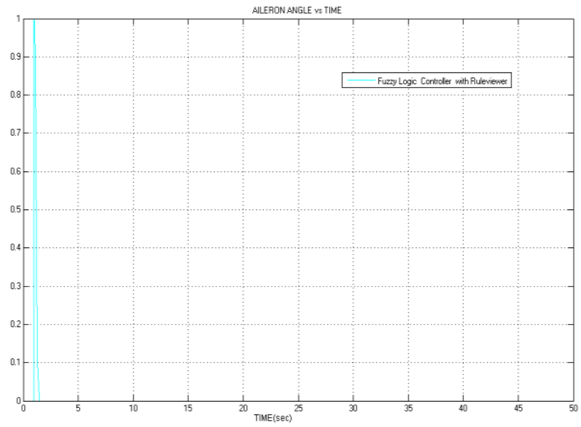

Fig.5.4(a) Step Output response of ANFIS controller for fighter aircraft showing Aileron deflection angle response with roll-rate-integrating gyro

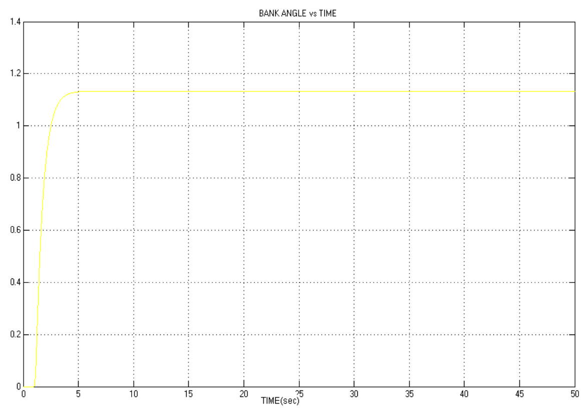

Fig.5.4(b) Step Output response of ANFIS controller for fighter aircraft showing Bank deflection angle response with roll-rate-integrating gyro

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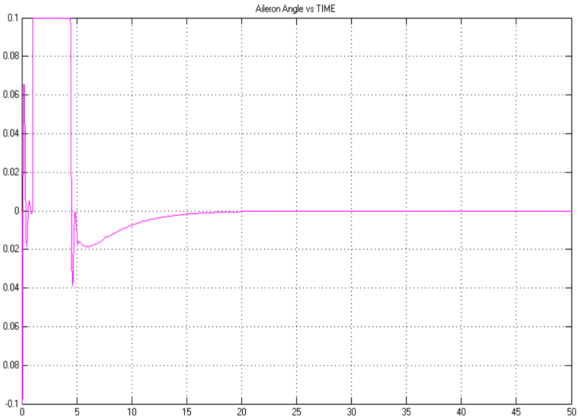

Fig.5.5(a) Step Output response of Fuzzy-PID controller for fighter aircraft showing Aileron deflection angle response with roll-rate-integrating gyro

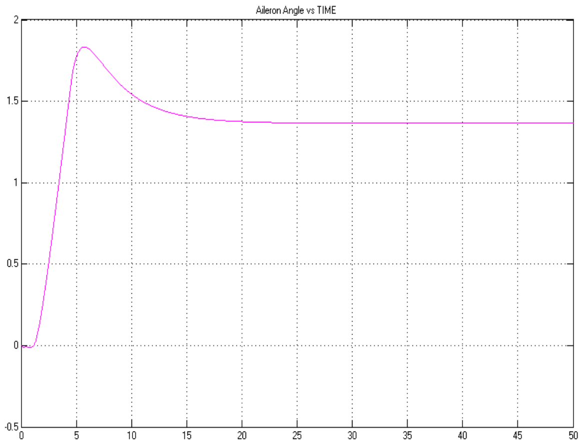

Fig.5.5(b) Step Output response of Fuzzy-PID controller for fighter aircraft showing Bank deflection angle response with roll-rate-integrating gyro

Tabel 5.1 Comparison of different controllers for aircraft roll control

PARAMETERS	CONTROLLERS				
	PID	ANN	FUZZY	ANFIS	FUZZY-PID
Settling Time	1.25 sec	2.2 sec	2.54 sec	2.52 sec	0.176 sec
Rise Time	0.322 sec	0.18 sec	1.43 sec	2.15 sec	0.116 sec
Overshoot	4.58 %	0%	0 %	0 %	1.48%

6.CONCLUSION

For aircraft roll control movement Fuzzy-PID controller handles the system far better than any other controller, providing best transient response, with minimum Settling Time, Rise Time and Overshoot. Although every controller is able to handle the process with accuracy, with aileron angle getting settled at zero reference point and aircraft bank angle getting settled at desired set point i.e., one, thus achieving the desired result.

Aileron Angle in all the controllers settles instantaneously and converges to 0˚ in steps indicating that the aileron angle of the aircraft is getting settled horizontally and this occurs as the aircraft achieves the commanded path.

Bank Angle also settles instantaneously and converges to 1set-point. Except ANN controller, which gives response in negative range, which can be neglected because it is in the tolerance band limit of 2% and very minor.

For Roll Angle there are two plots for each controller:

1. Plot between Aileron Angle vs Time.
2. Plot between Bank Angle vs Time.

For aircraft roll control movement all the controllers perform the desired task with maximum accuracy. But the combination of Fuzzy-PID controller with Fuzzy compensation technique provides best response when comparing all the parameters of time response specification.

Future Work

Some other intelligent and adaptive controllers such as Neuro-Fuzzy, Adaptive Fuzzy, ANN based controllers can also be employed for the problem undertaken in this report. Controllers used in this report can be optimized using various Optimization techniques such as Ant-colony optimization, Genetic Algorithm, Particle Swarm Optimization, Biogeography Based optimization etc. In this paper all the observation are made without taking into account the effect of disturbances which occur in the environment acting on a body of Aircraft in the air, such as Hydrodynamic forces, radiation force, Excitation force and Drag Force. Further the techniques implemented in the present work can also be implemented for Yaw control movement of aircraft. The following Parameters of Aircraft can also be designed using different intelligent techniques by considering details dynamics of the Aircraft.

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