International Journal of Hybrid Information Technology
Vol.9, No.4 (2016), pp. 139-150
http://dx.doi.org/10.14257/ijhit.2016.9.4.13

Attitude Control of Quadcopter Using Adaptive Neuro Fuzzy Control

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Abstract

This research contains the simulation and designing of Quadcopter using Adaptive Neuro Fuzzy Controller to control the altitude of quadcopter and obstacle detection. Now a day's advancement in technology has made it possible to develop low power and lightweight with accurate sensors which are used with controllers for controlling, which have high processing power but small power consumption. This has been allowed for the development of complex and difficult control systems that can be implemented onboard UAV. With this combination of high precision and light weight, real-time onboard navigation or guidance and autonomous flights are now practical. This research work used a Fuzzy controller to control the pitch angle of quadcopter and avoiding obstacles. The fuzzy controller receives the sensory data and adjust the pitch accordingly until unless it finds the clear path. For detecting obstacles the IR sensors are used. For designing a fuzzy inference system used Sugeno model and used mat lab commands to design ANFIS as we have another method for designing by using a Simulink as well. ANFIS designed is based on kinematics and dynamics equation of quadcopter that will be able to control the pitch of quadcopter. Simulations results in mat lab show that by using ANFIS the performance of Quadcopter will be improved significantly.

Keywords*: ANFIS, Quadcopter, Altitude Control, UAV, Fuzzy Controller, Obstacle detection, Sugeno model*

1. Introduction

Many existing work items theses and journals occurs on all aspects of quadcopter technology. Mostly researchers on quadcopters taken so far have focused on the model of kinematics and control needed to achieve stable flight. This model then has normally been used to develop a drone [1, 2].

Enough research has been done on micro-electro-mechanical systems (MEMS) inertial measurement units (IMU) s and microcontrollers typically used in a quadcopter. The issues related with the use of these systems in such a vehicle that have been studied.[3]

With this present work, it is easy to purchase a drone the shelf off and fly straight out of the box with little or no adjustment necessary.

Due to the non-linear behavior of the motion of the quadcopter more research has been done on the basis of simple linearization of nonlinear equations [4]. This linearization are essential errors, even if they let quadcopter to be controlled in a stable manner, not to make an correct calculation of the response of the quadcopter.

Sensors containing video cameras, infrared and ultrasonic rangefinders and further various equipment have been added to drones to make them anti-crash and to get them to perform robust maneuvers [5]. The complication of the control system employed using these systems can true autonomous flight, not only for one vehicle, but for more drones to coordinate with each other and complete tasks as a group [6].

ISSN: 1738-9968 IJHIT

Teppo Luukkonen explains the modeling and control of Quadcopter different control methods was studied, including PID controllers [7], backstopping control, LQR controllers and nonlinear controllers with nested saturation.

Mehdi Fatanl, *Lavi Sefidgari Bahram Ali Vatankhah Barenji* tries to explore an adaptive PID controller that can cause adaptive appropriate coefficients to control the height of quadcopter. The structure of the PID controller is analogous to artificial Neurons that is used in a large number of artificial neural networks. The attitude control of the quadcopter by the control device has been shown in a sine curve and the elimination of the perturbation by the incoming adaptive PID controller neuro was studied also [8].

Hossein Bolandi1, *Rezaei1 Mohammad Reza Mohsenipour*, *Hossein Nemati*, and *Seed Smailzadeh Majid* tried to control, stabilization and disturbance elimination of the attitude of quadcopter subsystem is discussed in his research. Analytical technique is proposed for tuning conventional PID control structure. Single Input Single output technique is used to the control structure to achieve the desired task. A comparison is made between the controller and the controller designed and back-step algorithm applied to the main model of quadcopter [9]

Mr. Lucas Argentim aims to present a comparison between the different controllers for use in a dynamic model of a platform quadcopter. [10] Controllers assumed in this book are a PID ITAE listening, classical LQR controller and a set with PID loop LQR. [11].

In this research, a new technique of Adaptive Neuro Fuzzy Controller for Quadcopter to make it robust, versatile and produce a low error steady state. The quadcopter will be able to fly on fixed height, avoid obstacles and change direction by changing its pitch angle accordingly. It will be able to stabilization and disturbance rejection attitude quad rotor subsystem.

2. Design of the System

In this chapter, designing of transfer function and the controller are explained. First the transfer function of the pitch model has been obtained by using matlab.

2.1. Design of Transfer Function for Pitch

For controlling the pitch movement of quadcopter we need transfer function so first we make state space matrix by using the equations after getting state space matrix by using mat lab command the transfer function of system is obtained. For checking the stability we plot root locus plot of our system which shows that all poles lies in left half plane.

2.1.1. State Space Equation of the System

Following are the state space equations of the system:

$$A = \begin{bmatrix} -0.9910 & 0 & -0.0396 & 9.8000 \\ 1.0000 & 0 & 0 & 0 \\ -3.2110 & 0 & -22.6700 & 0 \\ 0 & 0 & 1.000 & 0 \end{bmatrix} \quad \ldots\ldots(1)$$

$$B = \begin{bmatrix} 0 \\ 0 \\ 0.0605 \\ 0 \end{bmatrix} \quad \ldots\ldots(2)$$

$$C = [\ 1\ 0\ 0\ 0\ ] \quad \ldots\ldots(3)$$

$$D = [\ 0\ ] \quad \ldots\ldots(4)$$

Now we have to store the state space matrix by using a mat lab command:

sys=ss(A,B,C,D)

2.1.2. Transfer Function of the System:

Now we used matlab command to convert state space matrix to transfer function
>> [b,a]=ss2tf(A,B,C,D)
Now we got the nominator and denominator of transfer function

b =[0 0 -0.0024 0.5927 -0.0000]

a =[1.0000 23.6610 22.3387 31.4678 0]

>> **h=tf(b,a)**

This is transfer function we used for plant

$$T(s) = \frac{-0.002397\, s^2 + 0.5927\, s - 5.141e^{-19}}{s^4 + 23.66s^3 + 22.34s^2 + 31.47} \quad \text{.........................(5)}$$

2.1.3. System Stability Check:

If the value of z is 0 then the system is stable otherwise system is unstable.

z=isstable(h)

z = 0

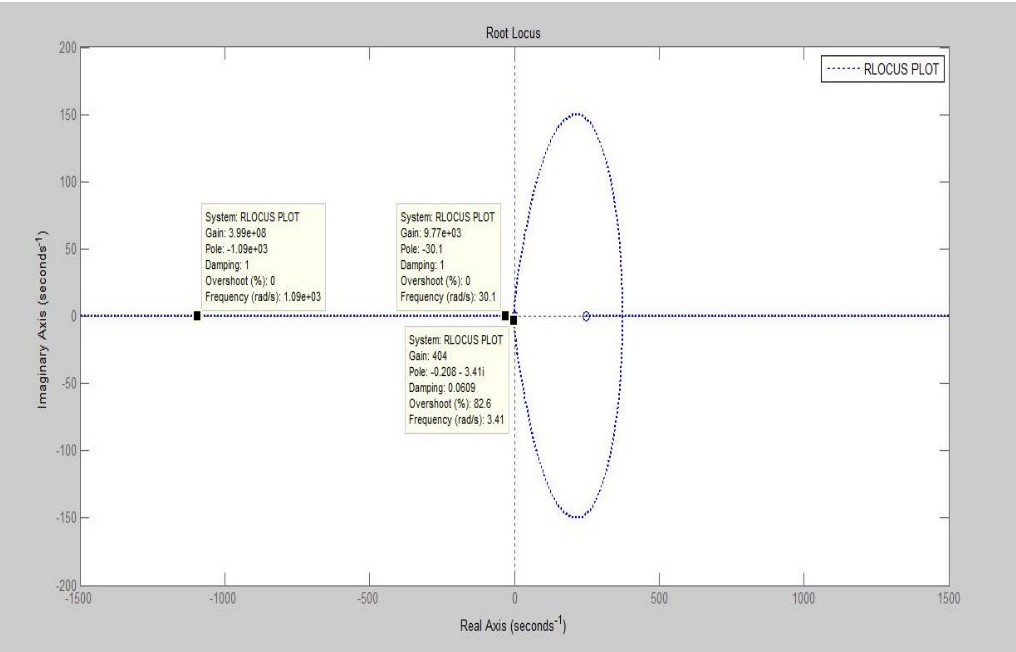

Figure 1. Root Locus Plot of the System

2.2. Design of tuned Fuzzy Controller

For the fuzzy inference system design we have two options for a Mamdani and the other is Sugeno. But the main problem is that in Mamadani ANFIS fuzzy inference system does not work if I use Sugeno system fuzzy inference.

The form chosen for membership function is triangular and use seven MF (membership functions) for every rotation angle and the membership function of range of pitch angel taken as -30 to 40. The membership function for each of the rotation angle are shown below.

Table 1. Membership Function of the Angle

	Membership Function of Angle
PL	Positive Large
PM	Positive Medium
PS	Positive Small
Z	Zero
NS	Negative Small
NM	Negative Medium
NL	Negative Large

The membership function plot is shown below

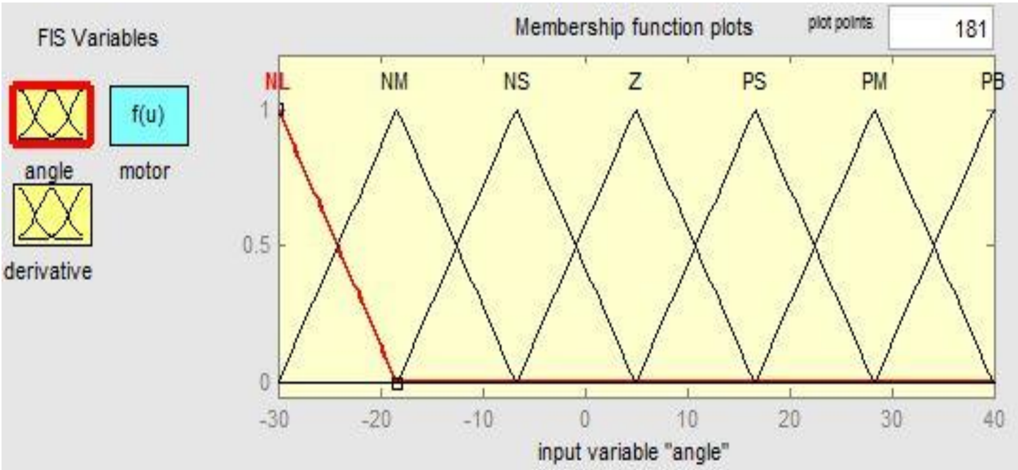

Figure 2. Membership Function Plot of the Angle

5 membership function has been used for angle derivative. Range for angle derivative taken is -10 to 30. Membership function for angle derivative are show below.

Table 2. Membership Function for Angle Derivative

	Membership Function for Angle Derivative
PM	Positive Medium
PS	Positive Small
Z	Zero
NS	Negative Small
NM	Negative Medium

Now shown below is the membership function plots for angle derivative

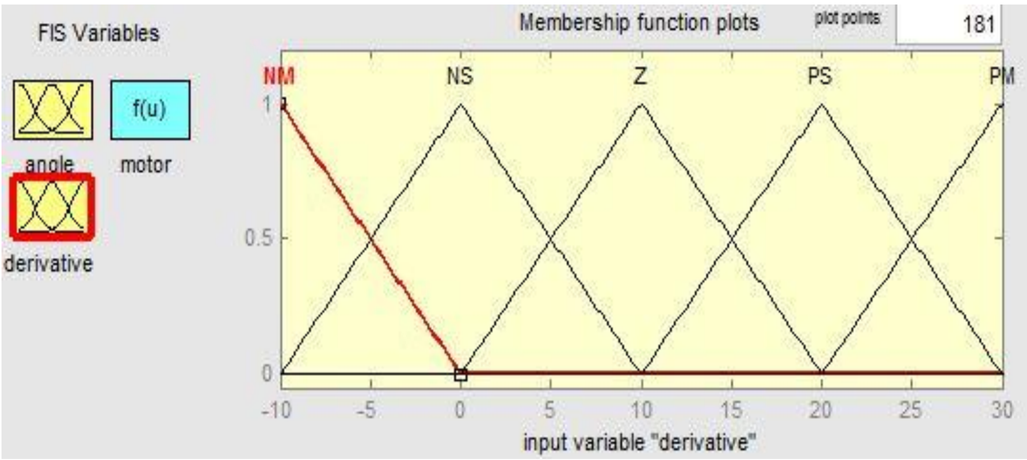

Figure 3. Membership Function Plots for Angle Derivatives

For output 9 membership function are defined. Membership function for output represent the PWM percentage. Membership function for outputs are defined below.

Table 3. Membership Function of Motors PWM

	Output Membership Functions for Motors PWM
PXL	Positive Extra Large
PL	Positive Large
PM	Positive Medium
PS	Positive Small
Z	Zero
NS	Negative Small
NM	Negative Medium
NL	Negative Large
NXL	Negative Extra Large

Now these are rules for fuzzy controller. Now If the Quadcopter has a Positive Large angle and its derivative has Positive medium angle then quadcopter need negative extra-large angle. Now if the quadcopter has zero value angle, straight on horizontal line, derivative is zero and it's not rotating then neither a motor 2 nor neither a 4 receive PWM. There are total 35 rules than can control the quadcopter pitch if angle input is changed there comes the difference in the motor PWM that is output as shown below.

Table 4. Rules for Fuzzy Controller

	PM	*PS*	*Z*	*NS*	*NM*
PL	NXL	NXL	NXL	NL	NL
PM	NXL	NXL	NL	NM	NS
PS	NXL	NL	NM	NS	PS
Z	NM	NS	Z	PS	PM
NS	NS	PS	PM	PL	PXL
NM	PS	PM	PL	PXL	PXL
NL	PL	PL	PXL	PXL	PXL

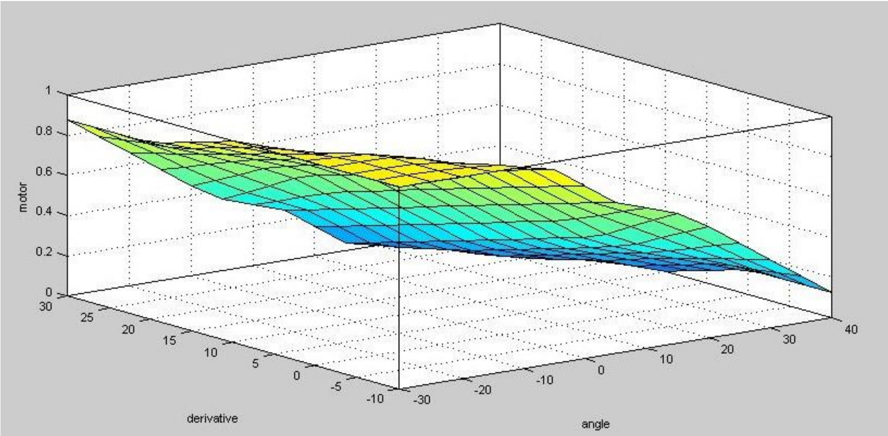

Figure 4. Surface Generated with Controller Design

This is my plant modal that we made it on Simulink we use transfer function in plant and control the gains of plant by fuzzy controller

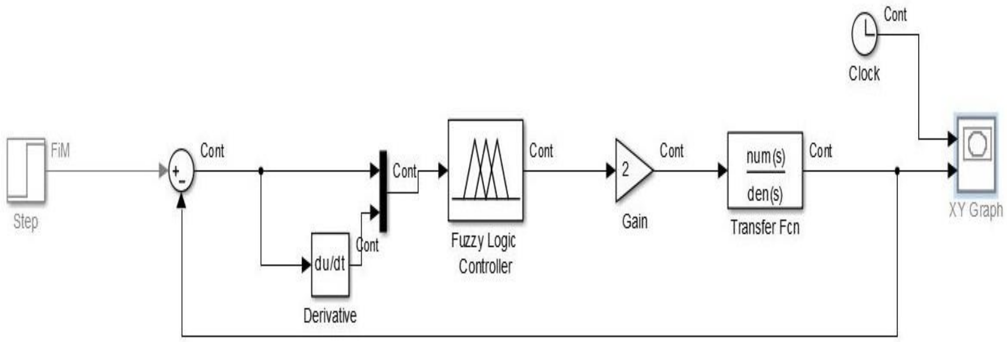

Figure 5- Simulink Model for Pitch of the Quadcopter

2.3. ANFIS

Following are the simulations of ANFIS controller of the system

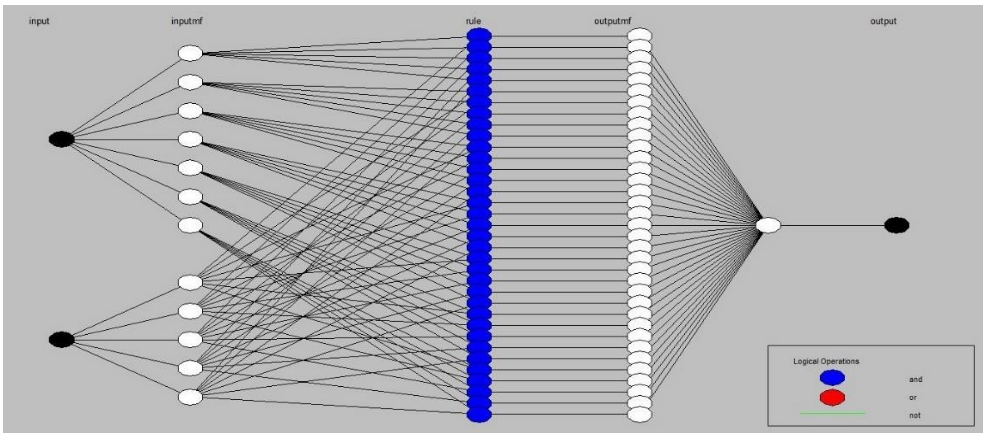

Figure 6. Structure of ANFIS

In the above figure the whole structure of ANFIS is shown. There are two inputs named pitch angle and its derivative is giving inputs where the second layer is showing the total number of input membership functions which is firing the rules the third layer is showing the total number of rules and fourth layer is showing total number of output membership functions and finally there is crisp value at output.

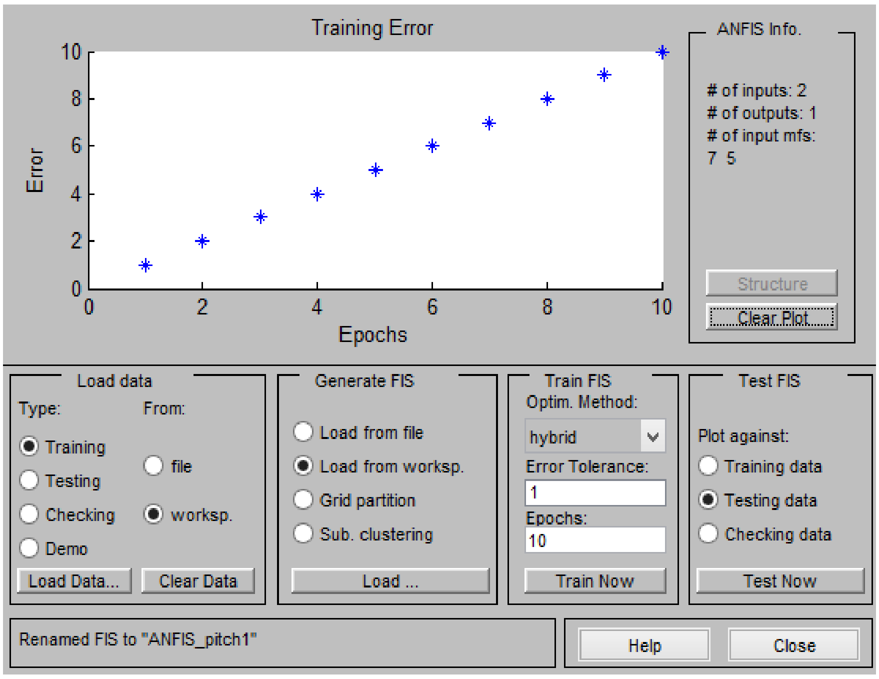

Figure 7. Training of ANFIS System

The above figure shows the training of ANFIS system here we trained pair of inputs and outputs after loading I/P and O/P then we load FIS after that we train our ANFIS system.

2.4. Obstacle Detection

For obstacle detection quadcopter receives the sensory data from the sensors and adjust the pitch angle accordingly until unless it finds the clear path. In this paper Takagai Sugeno fuzzy inference system has been used. Inputs will be obstacle detected by sensor and Outputs is pitch angle and Velocity of Quadcopter.

2.4.1. Membership functions for Inputs and Outputs

Membership function for obstacle input are V Near, Near and Far
Membership function for pitch outputs are Up and Small
Membership function for Velocity outputs are Small, Medium and Fast

2.4.2. Rules

Following are the rules:

- If Obstacle is V Near then theta is up and V_z is small
- If Obstacle is Near then theta is up and V_z is medium
- If Obstacle is Far then theta is zero and V_z Fast

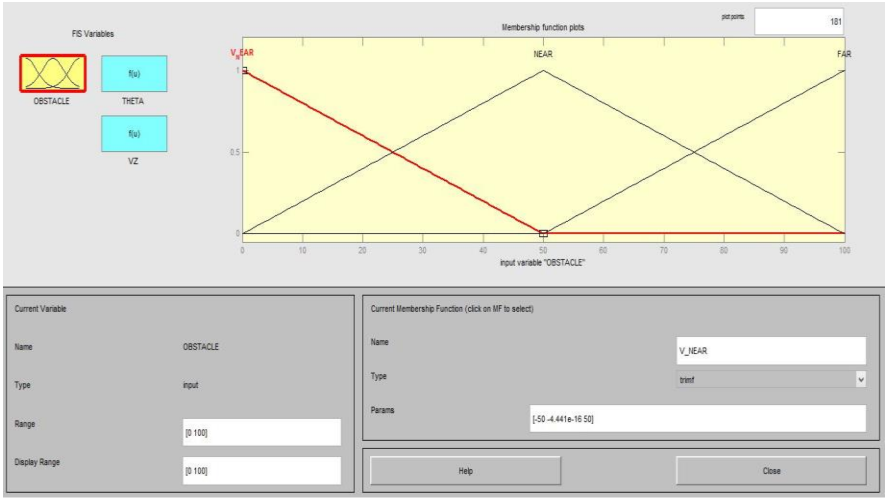

Figure 8. Membership Function Plot

3. Simulations and Results

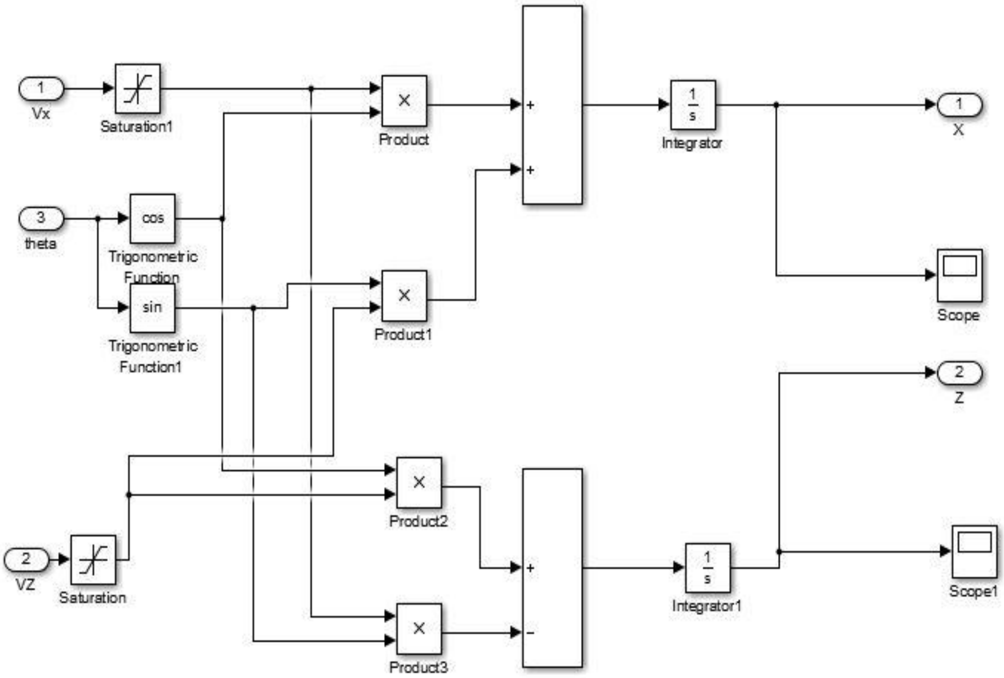

Figure 9. Plant Model for Quadcopter

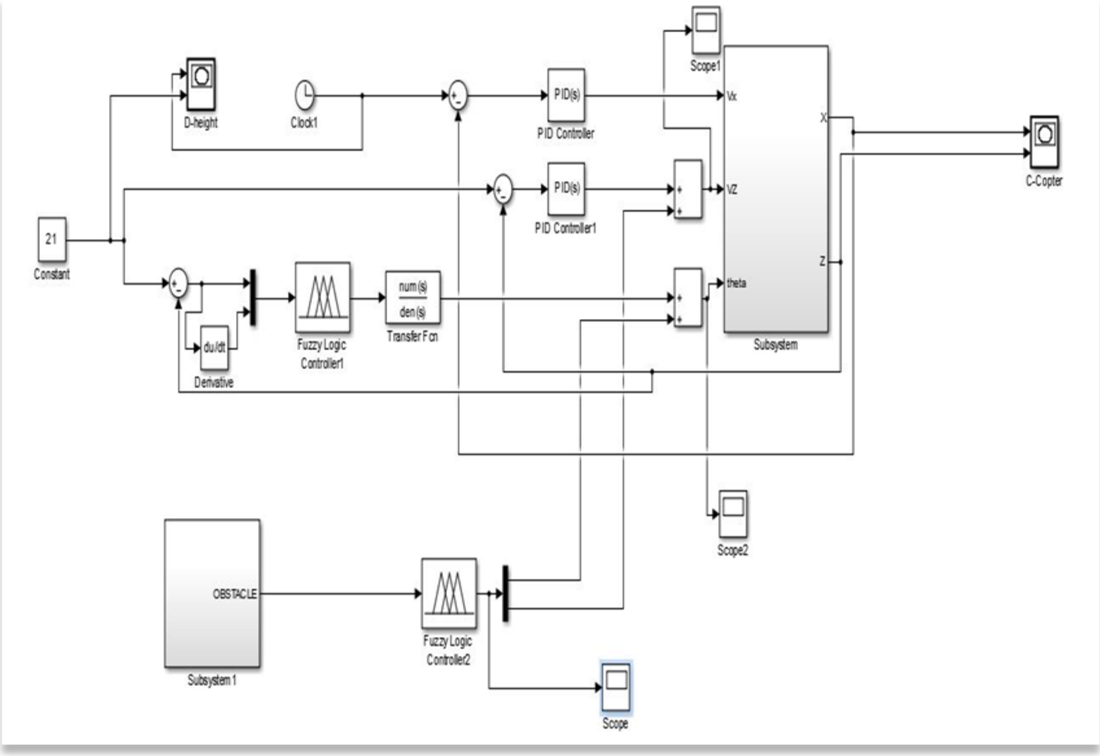

Figure 10. ANFIS Model for Altitude Control and Obstacle Avoidance

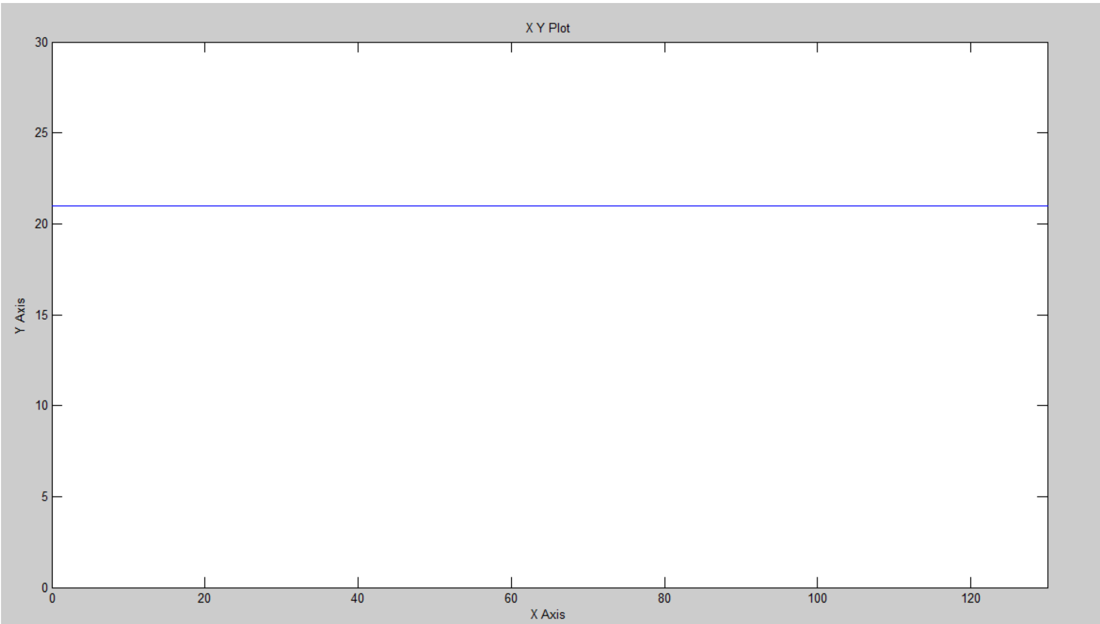

Figure 11. Desired Height of Quadcopter

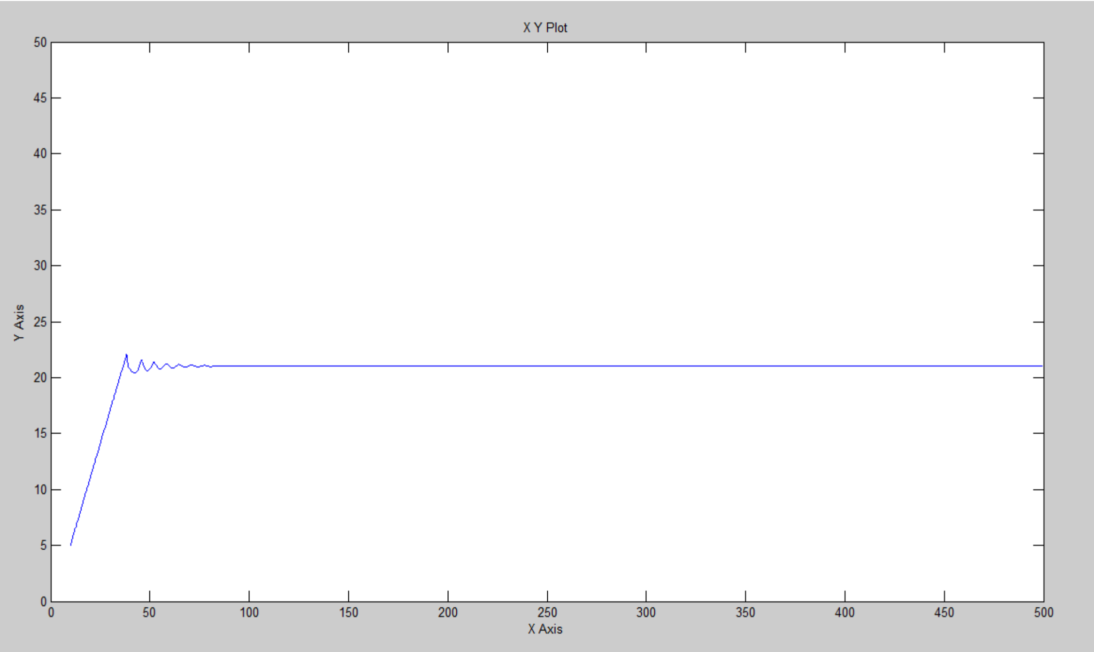

Figure 12. Quadcopter Graph Flying on Desired Height

4. Conclusion

This thesis presented the simulation and the testing of pitch control techniques for the attitude control of a quadrotor and obstacle detection. In this technique the transfer function of lateral control from state space is obtained then to control the pitch the fuzzy controller is used by introducing some membership function and rules and at output the crisp value of pitch angle is obtained.

Acknowledgment

Firstly, we would like to thanks to our advisor Prof Dr IM Qureshi for the continuous support of our research, for his patience and immense knowledge. His guidance helped us in all the time of research and writing. Second we would like to thanks to Air University for providing us opportunity to do the research.

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