TRAJECTORY TRACKING USING INTELLIGENT CONTROL TECHNIQUES

Project Report

Submitted By –

SERIAL NO. – **25**

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PROJECT VERIFICATION

The following Project Report is documented for the Electrical Engineering Course of EEN 300: Industry Oriented Project for the students of B. Tech, III Year.

The report is based on the Topic:

Trajectory tracking of a quadcopter using intelligent control techniques.

“

I have proofread and hereby verify that the following Project has been completed and done under my supervision and strict guidance.

I approve that all data, information & documents attached in the Report is under my knowledge and every single member of the group has contributed his share to the making of either of the IOP Project / Model / Report.

”

Signature of Supervising Faculty In-charge: ________________________

Name of Faculty In-charge: ________________________

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c. **Simulation results with Fuzzy Controller (before tuning)**

d. **Simulation results with Fuzzy Controller (after tuning) for given reference trajectories**

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ABSTRACT

The main vision regarding this project is to incorporate an intelligent system using Fuzzy Logics to improve the trajectory tracking of a model of Quadcopter. A quadcopter is a complex model system which uses four rotors to stabilize and control its motion. The different speeds of the rotors are the main reason for the trajectory of the quadcopter. The control of the motor speeds according to the requirement of motion is very complex and difficult. A quadcopter has a total of 6 degree of freedoms. Three of which are due to their position (coordinates) in the space – x(horizontal), y (vertical) and z (height) axis and the other three is due to their orientation (angle) along these axis – roll, pitch and yaw. The fuzzy model created is developed and implemented with the purpose to control its trajectory and improve its efficiency using intelligent control strategy. The inputs to the system are the reference x, y and z points and the yaw angle. The outputs are the state space matrix giving the values of the coordinates reached and the other parameters calculated according to the mechanics of the quadcopter. This output helps us to calculate the errors which are reduced using the Fuzzy Logic Controller to improve its trajectory.

INTRODUCTION

One of the most used robotic platforms in the world is autonomous helicopters because of their ability of vertical take-off and vertical landing as well as stationary flight movement. They are useful in various situations like natural disasters, rescue missions, field or structure inspections, transportation of materials to remote areas, making geographical maps and so on. Many times, these situations involve risks and require some particular characteristics like high mobility and small size helicopters. This report represents the developed design and a simulation in MATLAB of a quadcopter controlled using Fuzzy Logic Controller (FLC) for better efficiency. The report gives a comparison between the trajectory obtained using fuzzy logics and PID controller.

The main advantage of quadcopter over a standard helicopter is the stability of the vehicle. The disadvantage is the control of all the four rotors in the quadcopter for the trajectory simultaneously. The proposed strategy of intelligent control is fuzzy one. That is, it takes the advantage of fuzzy logic's facility to implement the rules for control actions.

This report is organized as follows:

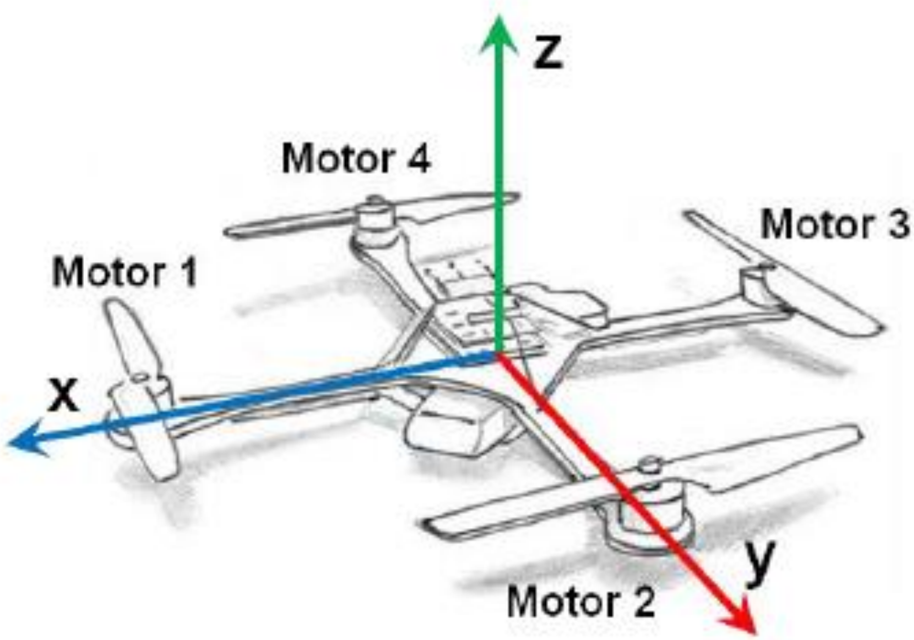
Section 3, briefly describes the quadcopter model and its characteristics. Section 4, tells about the design of the fuzzy controller and the rules. Section 5 shows the simulation results for different testing trajectories. Finally, in Section 6 the conclusions are presented.

DESCRIPTION OF THE SYSTEM

In a quadcopter, the four rotors are symmetrically distributed with respect to the central cabin. The main parameters for the quadcopter designed in this report are:

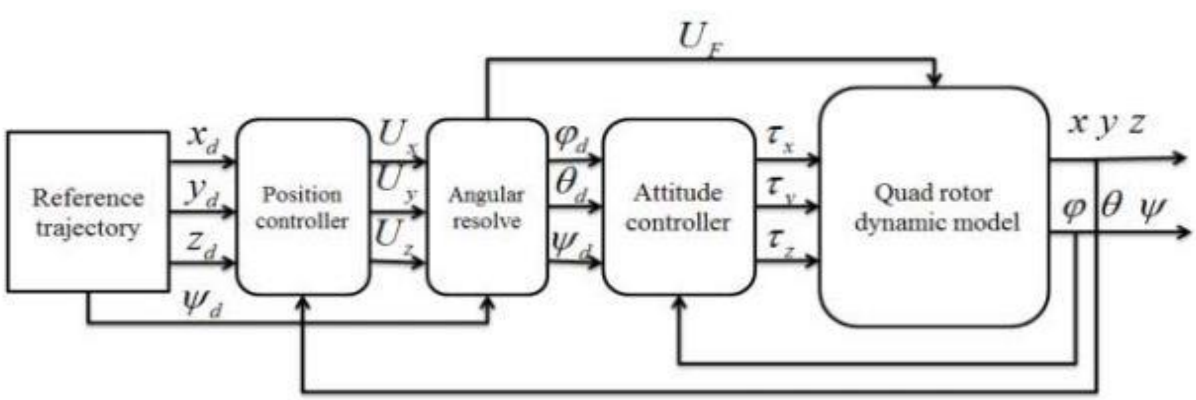
Gravity constant ‘g’	**9.8100 m/s^2**
Distance between one rotor and Centre of Mass	**0.2223 m**
Mass of the quadcopter	**1.0230 kg**
Moment of Inertia along X and Y axis is equal ($J_x = J_y$)	**0.0095 kg-m^2**
Moment of Inertia along Z axis (J_z)	**0.0186 kg-m^2**
Mass of one rotor	**0.0730 kg**
Distance of a rotor from center	**0.2223 m**
Height of the rotor	**0.0318 m**
Radius of the rotor	**0.0140 m**

The plus configuration we use is defined as having the X axis lie along the arm of motor 1 (which spins counter-clockwise from above, by our convention) with the Y axis set along the arm of motor 2 (spinning in the opposite direction of the adjacent motors) and the Z axis pointing upward. The value d represents the distance from a given motor to the axis of rotation and should be the same for every motor.



“+” Configuration

This report consists of trajectory tracking controller for Quadcopter using SIMULINK whose schematic diagram is shown below:



Here is the PC (Path Controller) quadcopter model explained below in steps:

1. **PC quadcopter model is a path command model to track the position of the quadcopter. It takes path command input as the reference trajectory in the form of time-series data of coordinates (x,y,z) and psi (yaw) angle. When we first open the Simulink model, Figure-1 model is displayed.**
2. **First block is the *"Position Controller block"* whose schematic is shown in Figure-2. This block transforms reference values (x,y,z) and psi (yaw) angle to roll, pitch and yaw angle values with the help of feedback through output which are further used in state space modeling.**

$$e_x = x_d - x$$

$$e_y = y_d - y$$

$$e_z = z_d - z$$

$$U_x = k_{px} e_z + k_{dx}\, \dot{e}_x$$

$$U_y = k_{py} e_y + k_{dy}\, \dot{e}_y$$

$$U_z = k_{pz} e_z + k_{dz}\, \dot{e}_z$$

$$U_x = \frac{U_f}{m}(\cos\Psi\sin\theta\cos\phi + \sin\Psi\sin\phi)$$

$$U_y = \frac{U_f}{m}(\sin\Psi\sin\theta\cos\phi - \cos\Psi\sin\phi)$$

$$U_z = \frac{U_f}{m}\cos\theta\cos\phi$$

$$U_f = \frac{m}{\cos\theta\cos\phi}U_z$$

$$\phi_d = \sin^{-1}\left(\frac{m}{U_f}U_x\sin\Psi_d - \frac{m}{U_f}U_y\cos\Psi_d\right)$$

$$\theta_d = \sin^{-1}\left(\frac{m}{U_f}U_x\cos\Psi_d + \frac{m}{U_f}U_y\sin\Psi_d\right)$$

$$\Psi_d = \Psi_d$$

3. Second block is "*Attitude Controller*" where the fuzzy logic controllers have been implemented with the respective error and its derivatives as input and final correction term as output. Attitude Control block is shown in Figure-3. Four Fuzzy logic controllers have been implemented each for roll correction, pitch correction, yaw correction and Z correction. State space parameters taken as inputs and correction term outputs are clearly shown in the figure.
4. Figure-4 shows the block diagram for error rotations of position controller.

$$U_f = \sum_{i=1}^{4} F_i = (F_1 + F_2 + F_3 + F_4)$$

$$\tau_x = l(F_2 - F_4) = bl(\Omega_2^2 - \Omega_4^2)$$

$$\tau_y = l(F_3 - F_1) = bl(\Omega_3^2 - \Omega_1^2)$$

$$\tau_z = (-1)^{i+1}\sum_{i=1}^{4} M_i = (M_1 - M_2 + M_3 + M_4)$$

$$= d(\Omega_1^2 - \Omega_2^2 + \Omega_3^2 - \Omega_4^2)$$

5. Figure-5 to Figure-8 depicts the block diagram for Fuzzy logic controller of roll, pitch, yaw and Z correction respectively.
6. Figure-9 is the "Quadcopter Control Mixing" block which converts roll correction, pitch correction, yaw correction and Z correction to motor correction terms for generating further motor inputs and respective equations are implemented as shown in Figure-10.
7. Figure-11 is the "Quadcopter Dynamics Block" in which the State space model of quadcopter dynamics has been implemented. Using this State space model, "Motor Dynamics Block" has been implemented and shown in Figure-12.

We have implemented the dynamic model of a quadcopter using MATLAB & SIMULINK whose schematic diagrams are shown below:

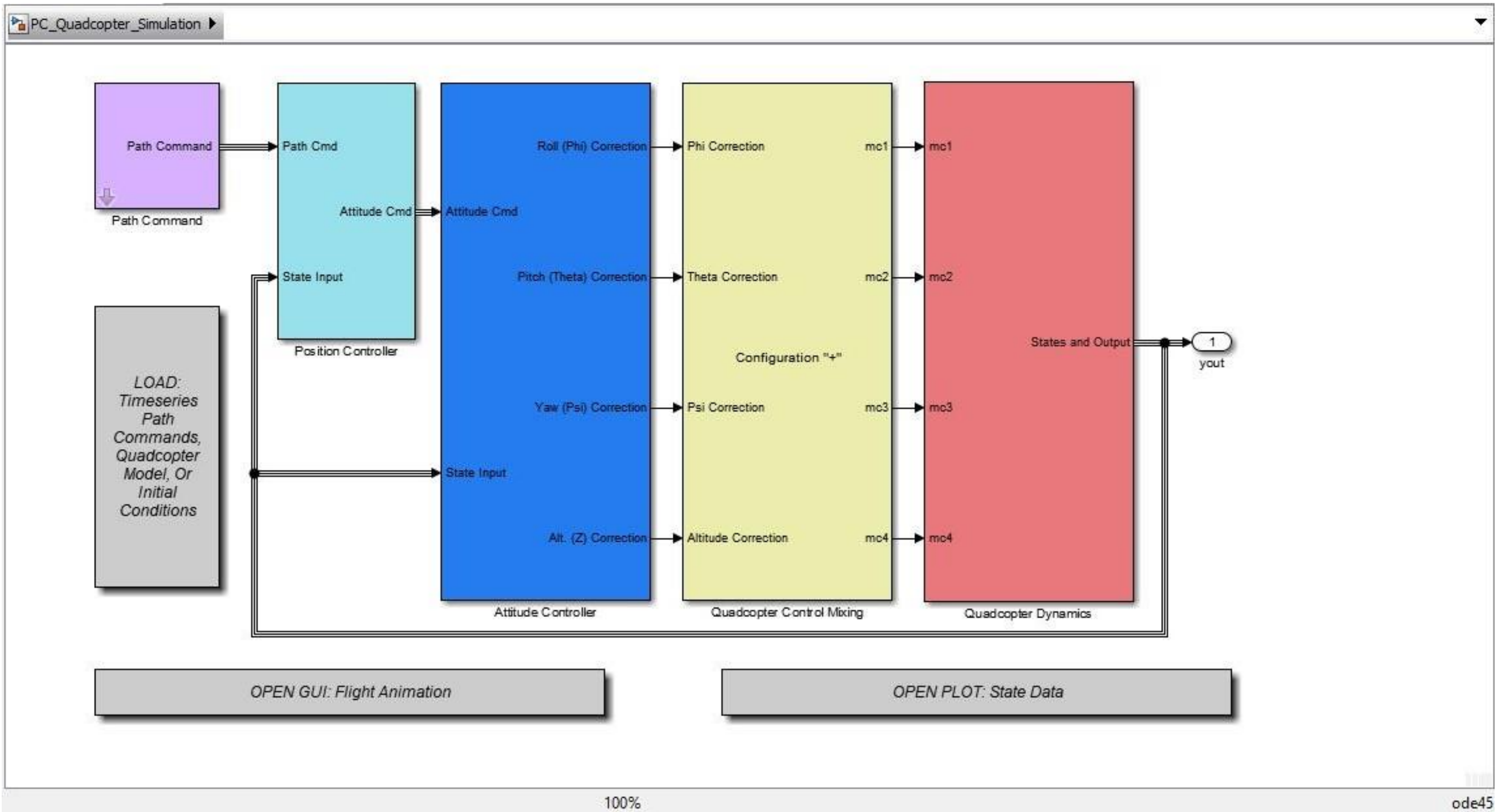


Figure 1: PC Quadcopter

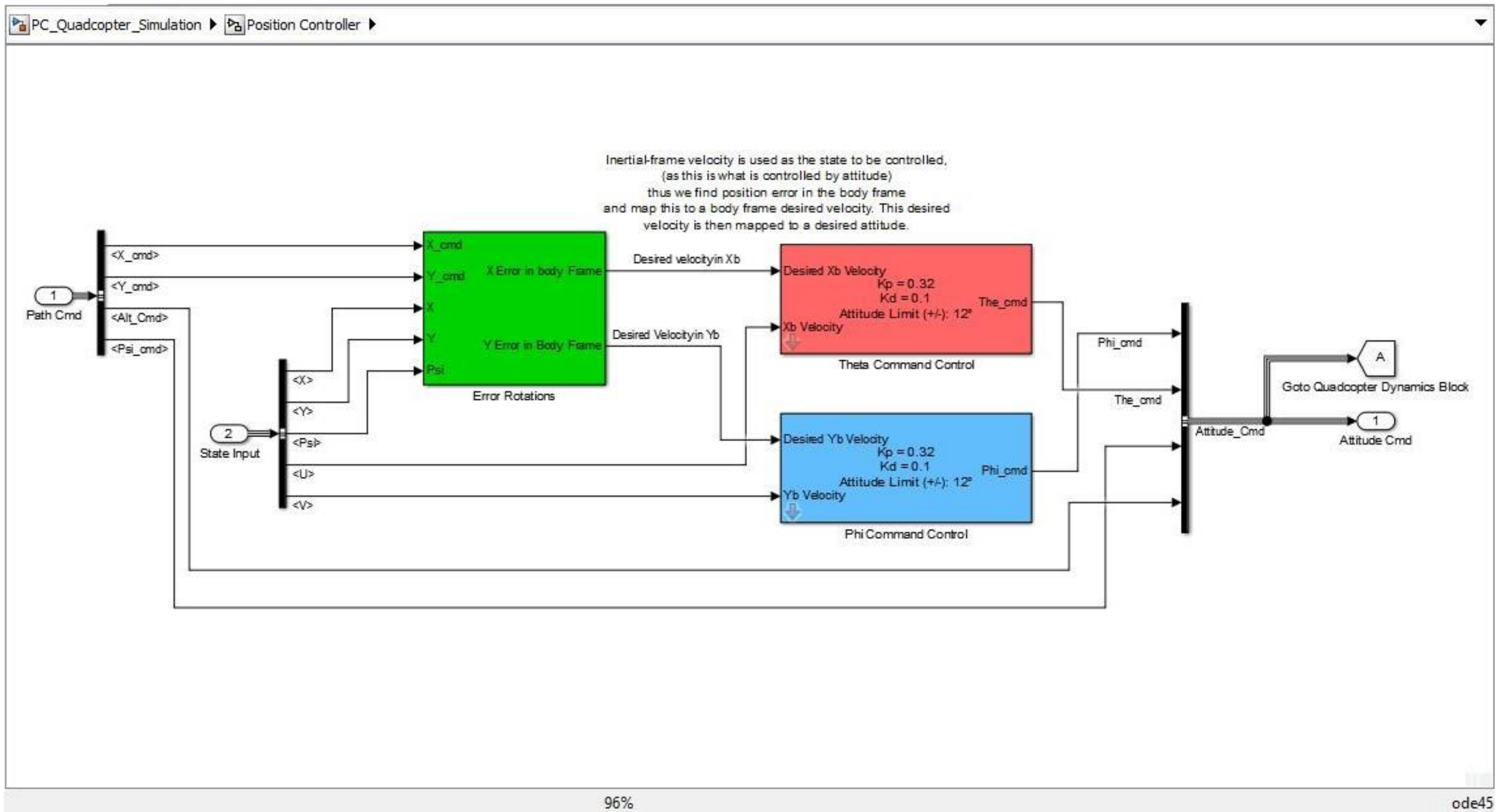


Figure 2: Position Controller

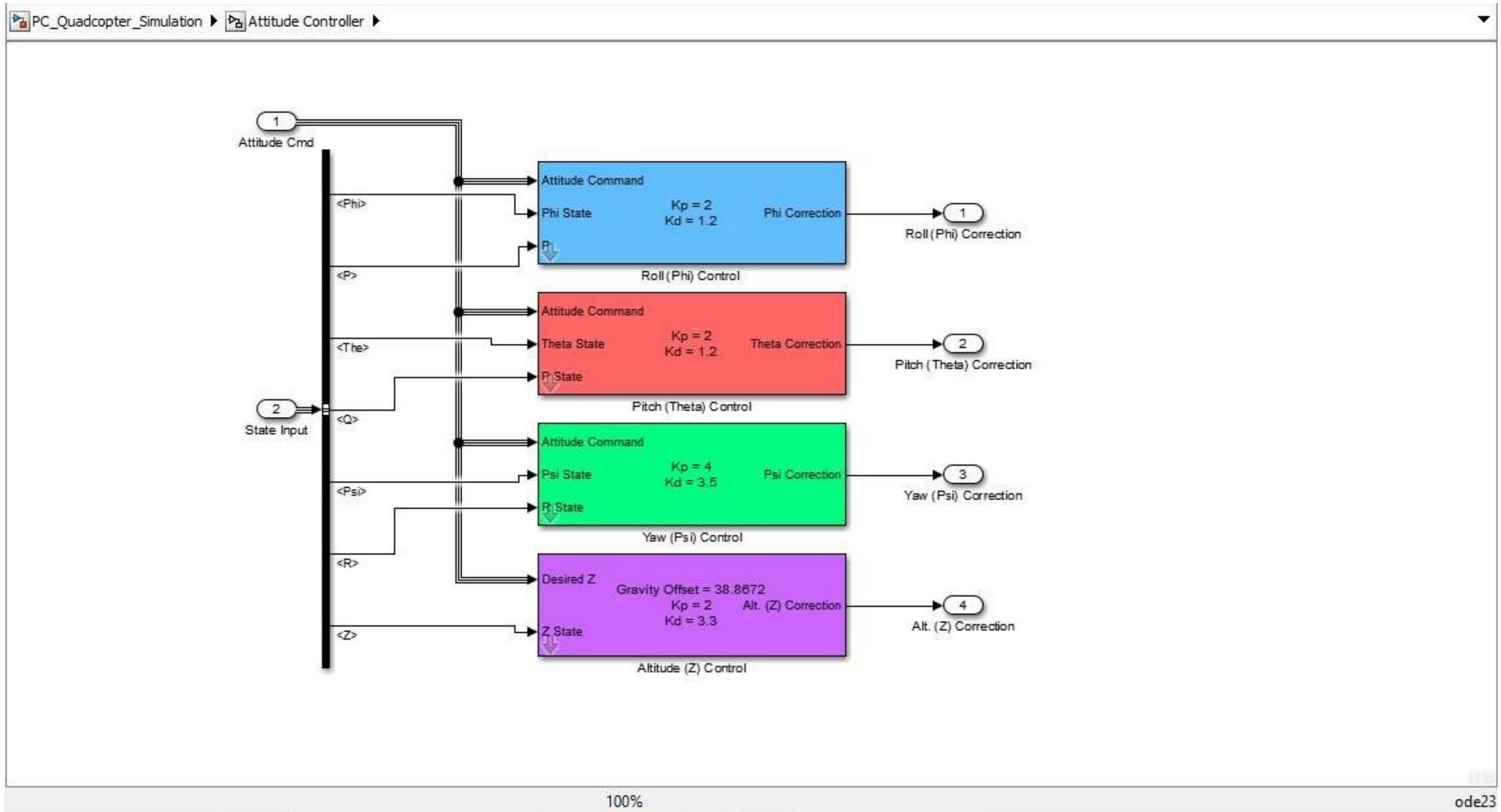


Figure 3: Attitude Controller

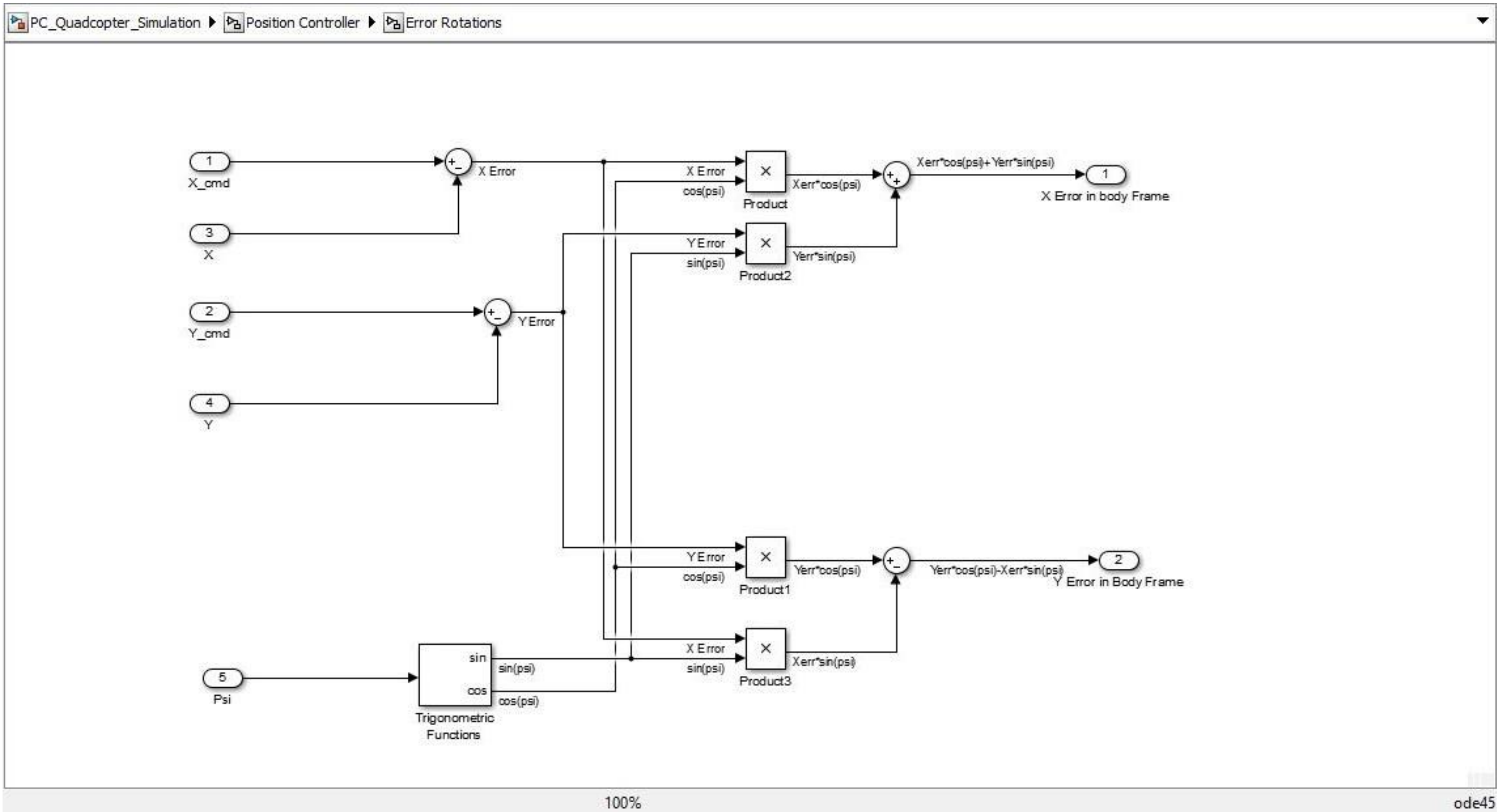


Figure 4: Error Rotations of Position Controller

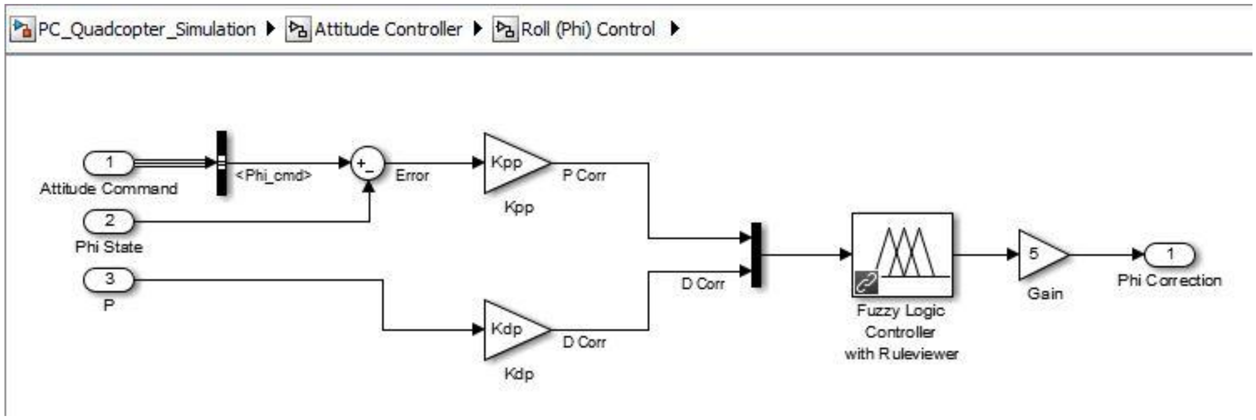


Figure 5: Fuzzy Logic Controller of Roll (Phi)

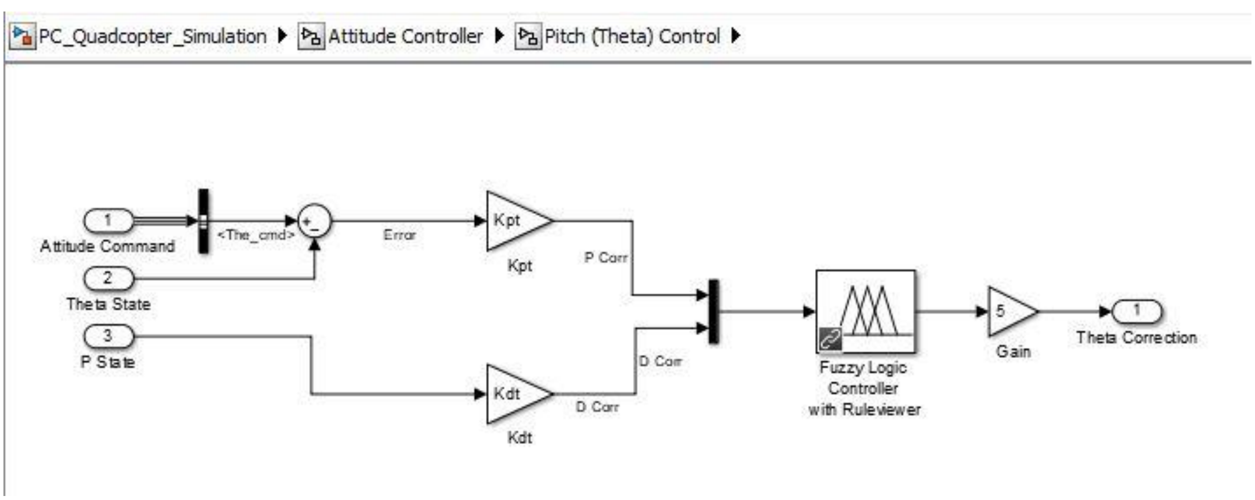


Figure 6: Fuzzy Logic Controller of Pitch (Theta)

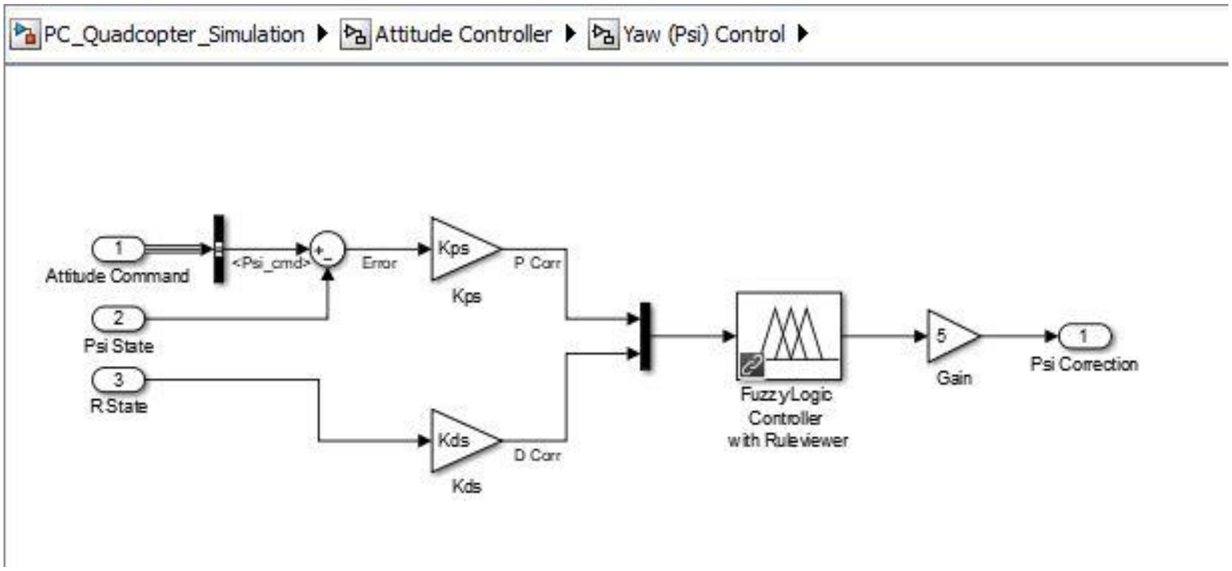


Figure 7: Fuzzy Logic Controller of Yaw (Psi)

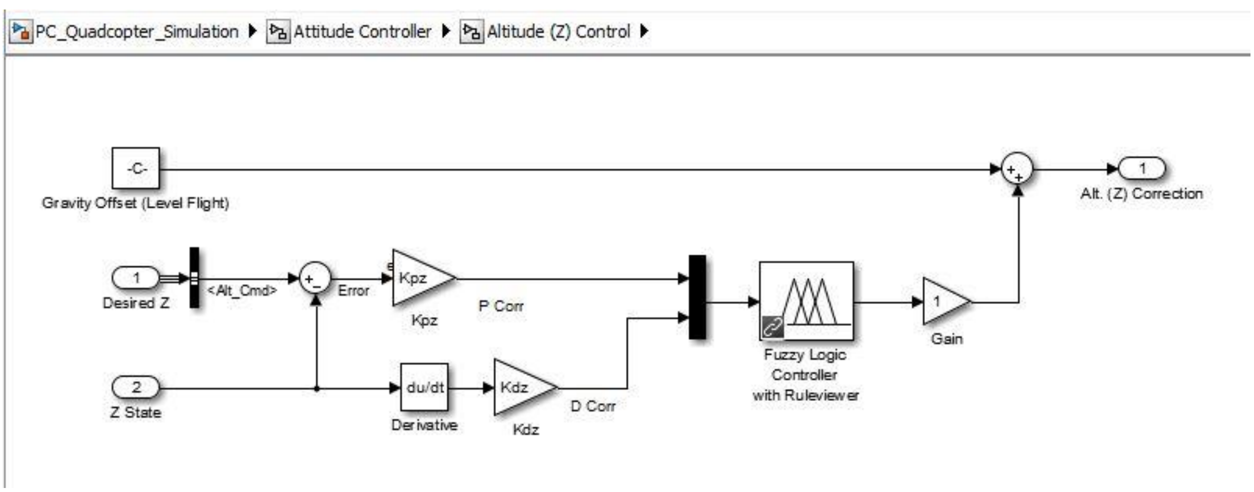


Figure 8: Fuzzy Logic Controller of Altitude (Z)

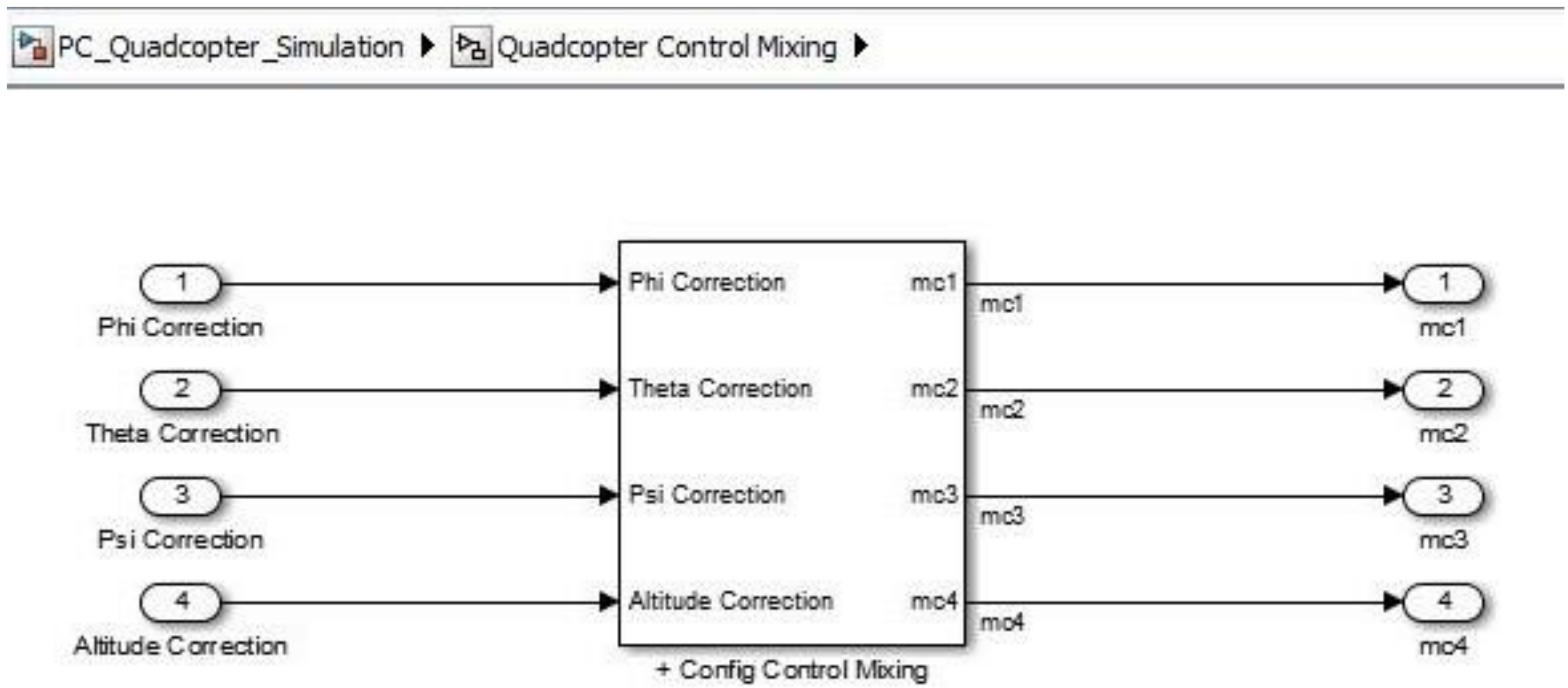


Figure 9: Quadcopter Configuration Control

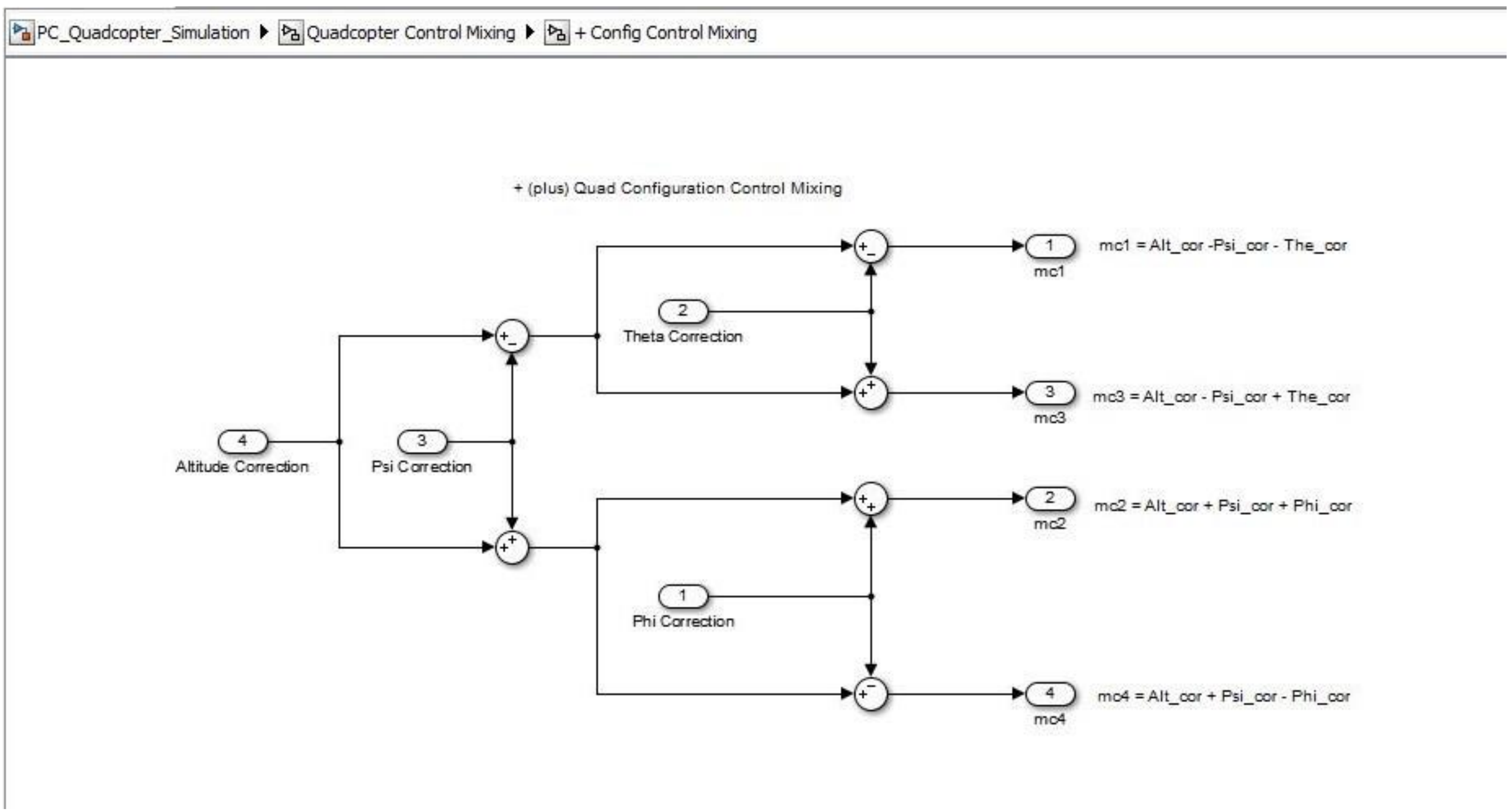


Figure 10: '+' Configuration control mixing

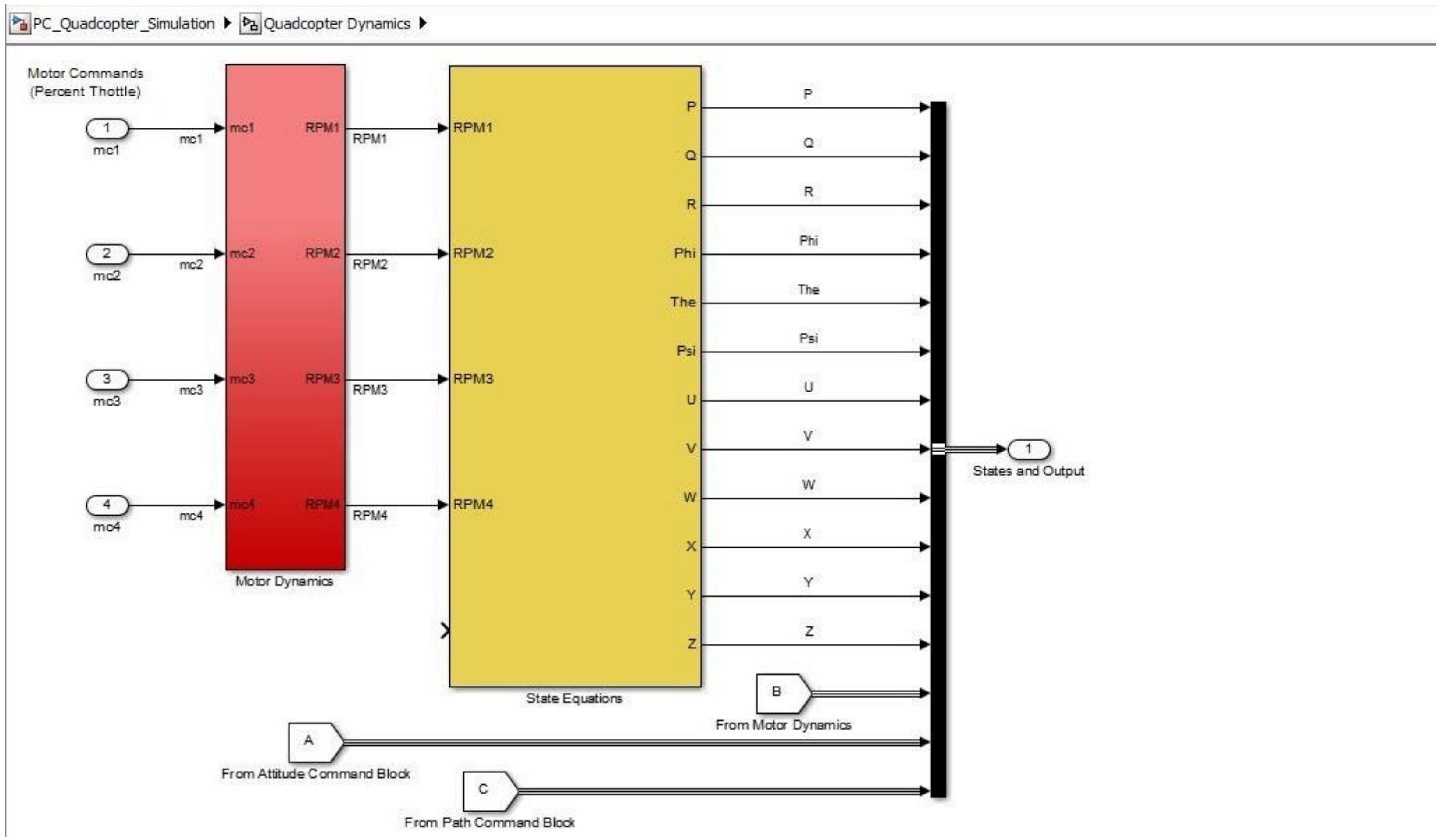


Figure 11: Quadcopter Dynamics

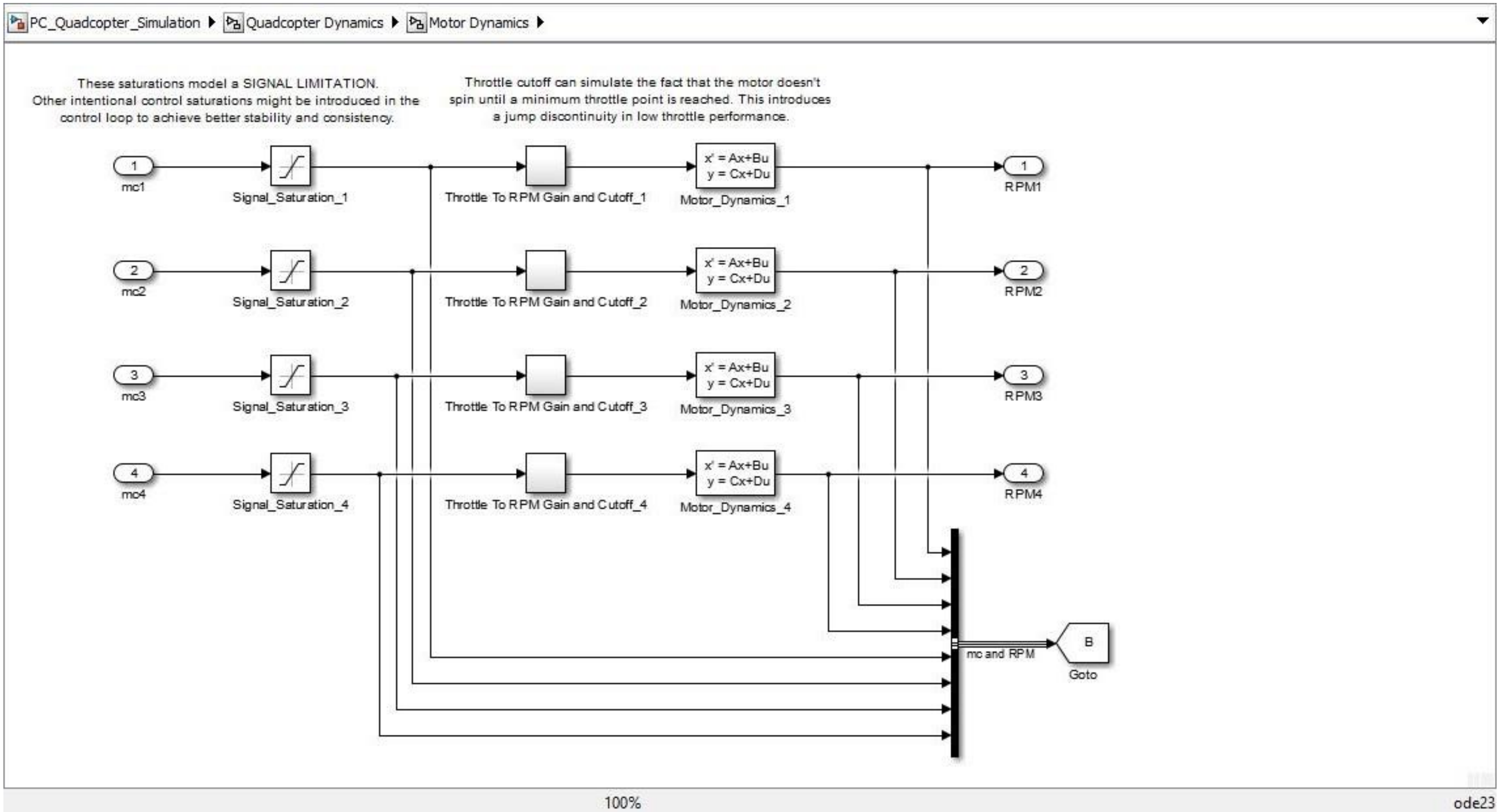


Figure 12: Motor Dynamics

INTELLIGENT FUZZY CONTROL

The fuzzy controller as shown in the Simulink model shows implementation of 4 block of fuzzy logic control in roll, pitch, yaw and height. The implementation of all the four Fuzzy Logic Controller in these blocks include two inputs which consists of the input 1 being the error of the reference value with the output value and input 2 being the error derivative and these two inputs give single output with the help of these 25 rules. Both the inputs consist of 5 membership functions (MF) each and the output consists of 5 membership functions.

Error_dr **Error** →

Error_dr ↓ \ Error →	NB	NS	Z	PS	PB
NB	NS	PS	PB	PB	PB
NS	NB	NS	PS	PB	PB
Z	NB	NS	Z	PS	PB
PS	NB	NB	NS	Z	PS
PB	NB	NB	NB	NS	Z

The ranges of the inputs for the fuzzy logic controller are set by checking the ranges of the PID error and error derivative telling the variation of the error and error_derivative of the roll, pitch, yaw and height.

The ranges are given in the next table calculated using the PID controller on the model created in SIMULINK and checking the output in the scope and plotting it which are shown below.

	error Range	error_derivative Range
Roll	-0.1 to 0.1	-0.1 to 0.1
Pitch	-0.1 to 0.1	-0.1 to 0.1
Yaw	-0.002 to 0.002	-0.001 to 0.001
Attitude	-0.04 to 0.04	-0.12 to 0.06

The aim behind using Intelligent Control System is to improve trajectory tracking for Quadcopter with following advantages:

1) This approach can be applied to various control systems with complex dynamics while ensuring stability of the systems;

2) It requires no prior knowledge of the trajectory system to modify the rules and this method can be applied to any unseen trajectories without any adaptation process; and

3) With wise feature selection, this approach can be computationally efficient with a very small model while demonstrating good performance on general trajectories.

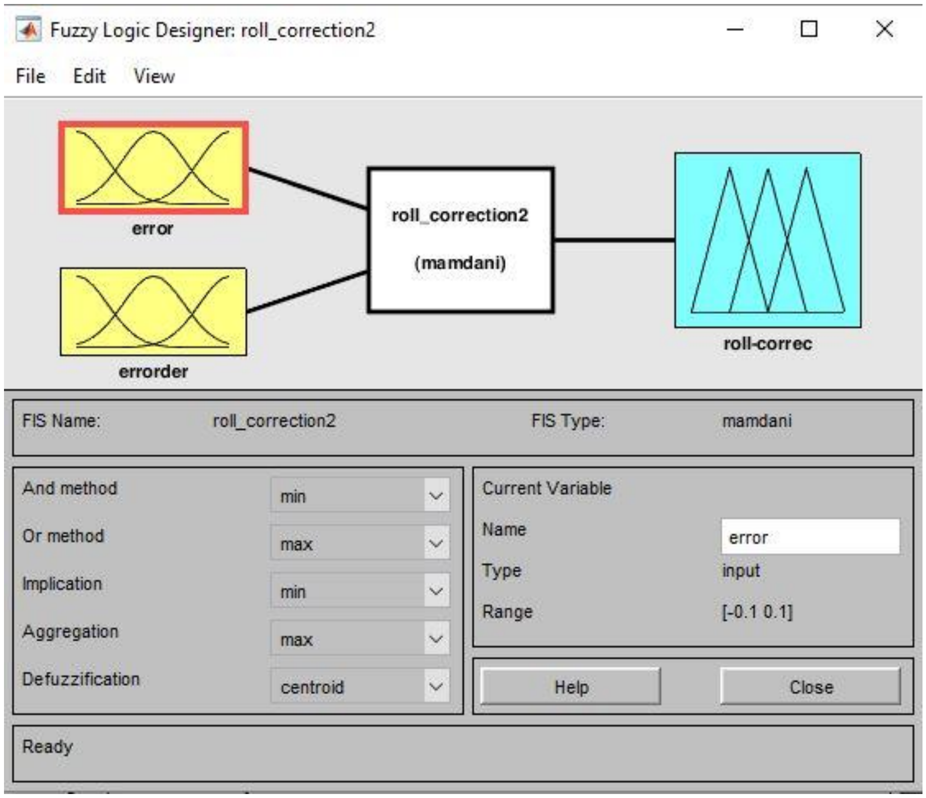


Figure 13: FLC of the roll correction

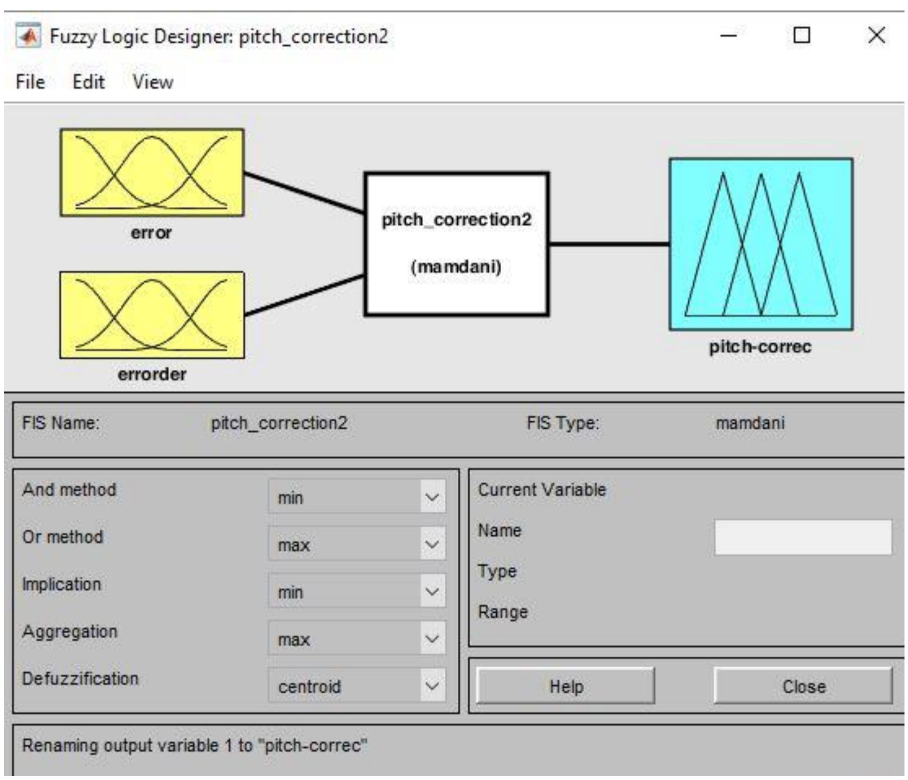


Figure 14: FLC of the pitch correction

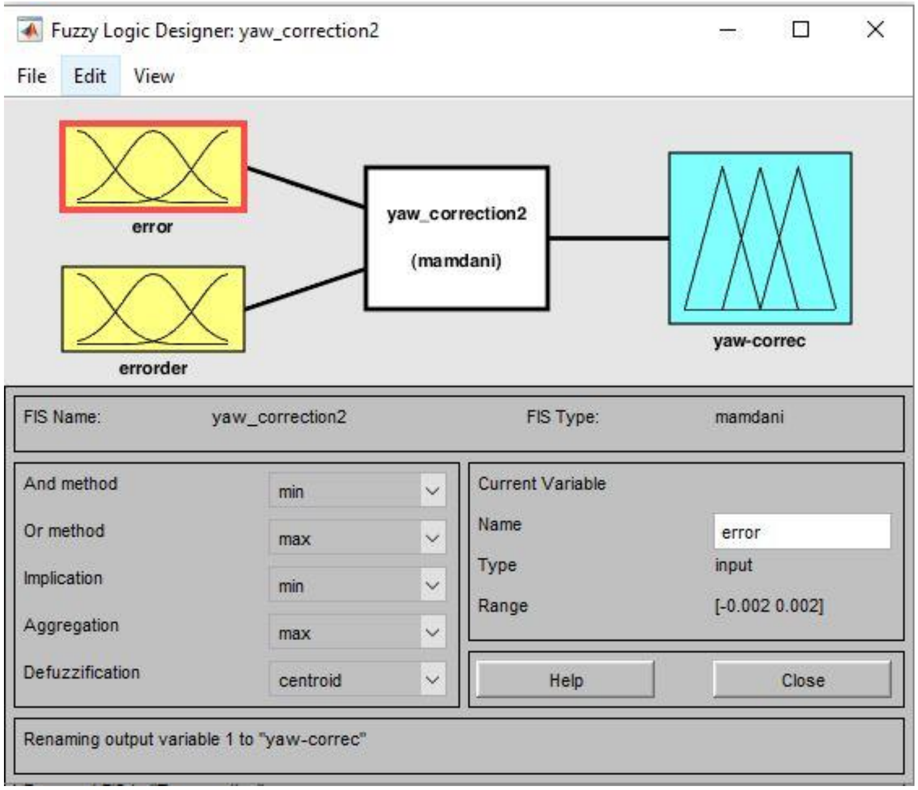


Figure 15: FLC of the yaw correction

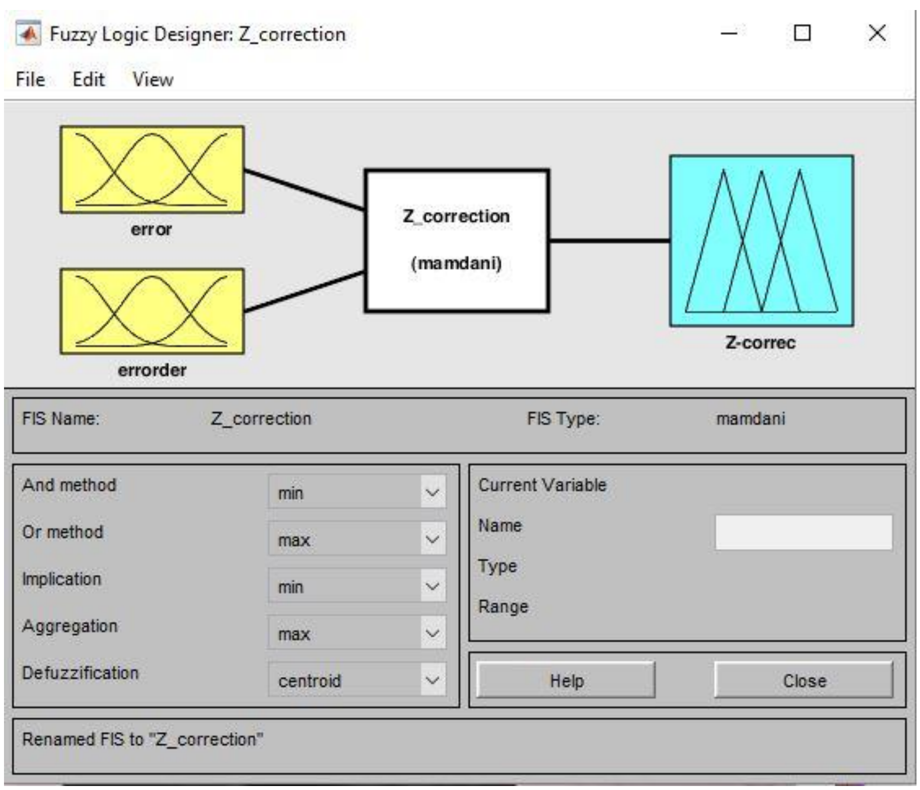


Figure 16: FLC of the Z correction

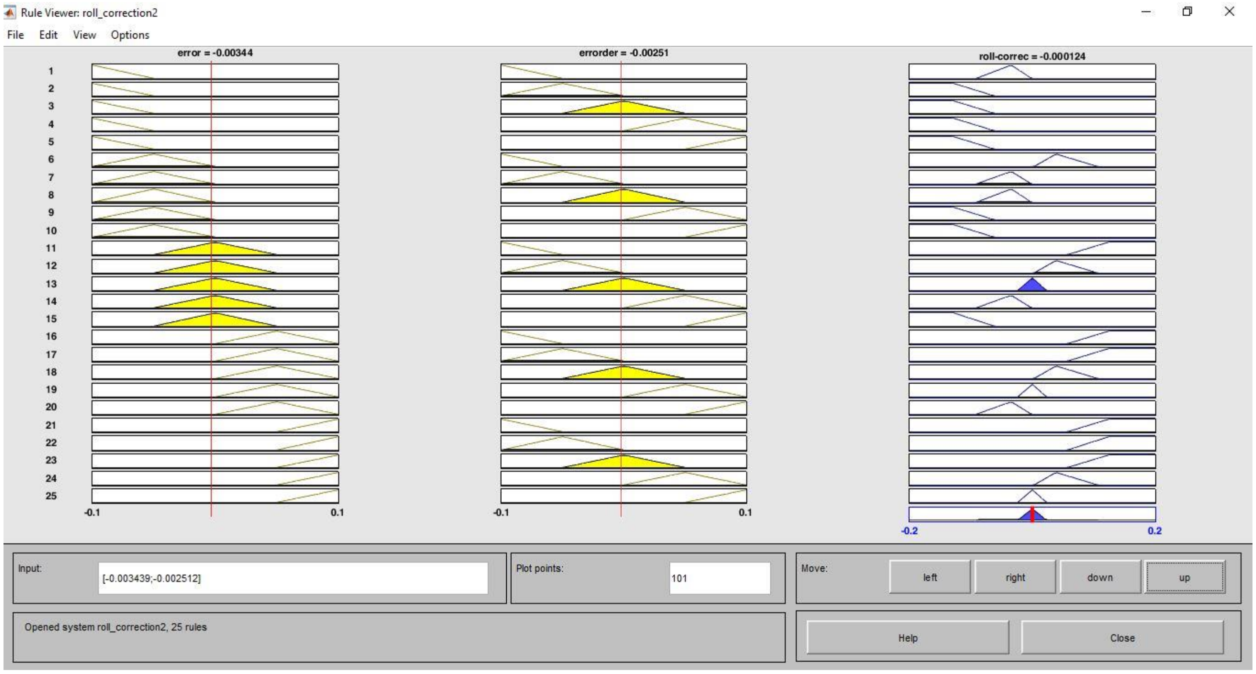


Figure 17: Rule viewer of the FLC on roll correction

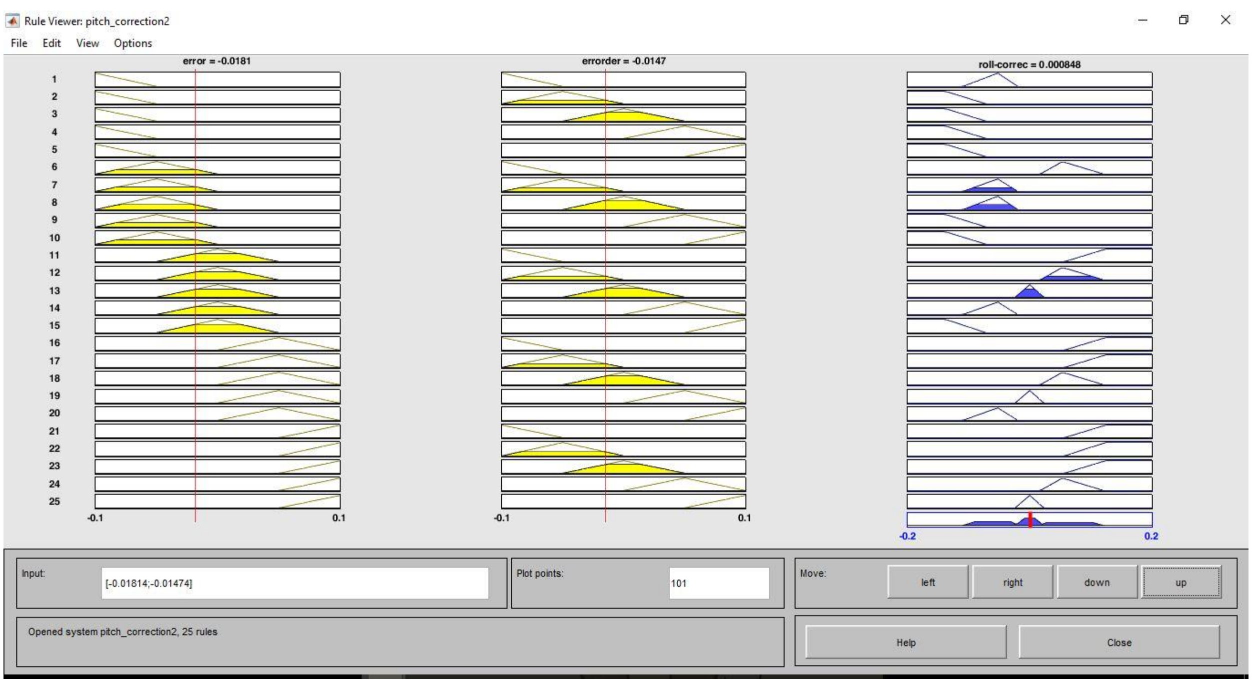


Figure 18: Rule viewer of the FLC on pitch correction

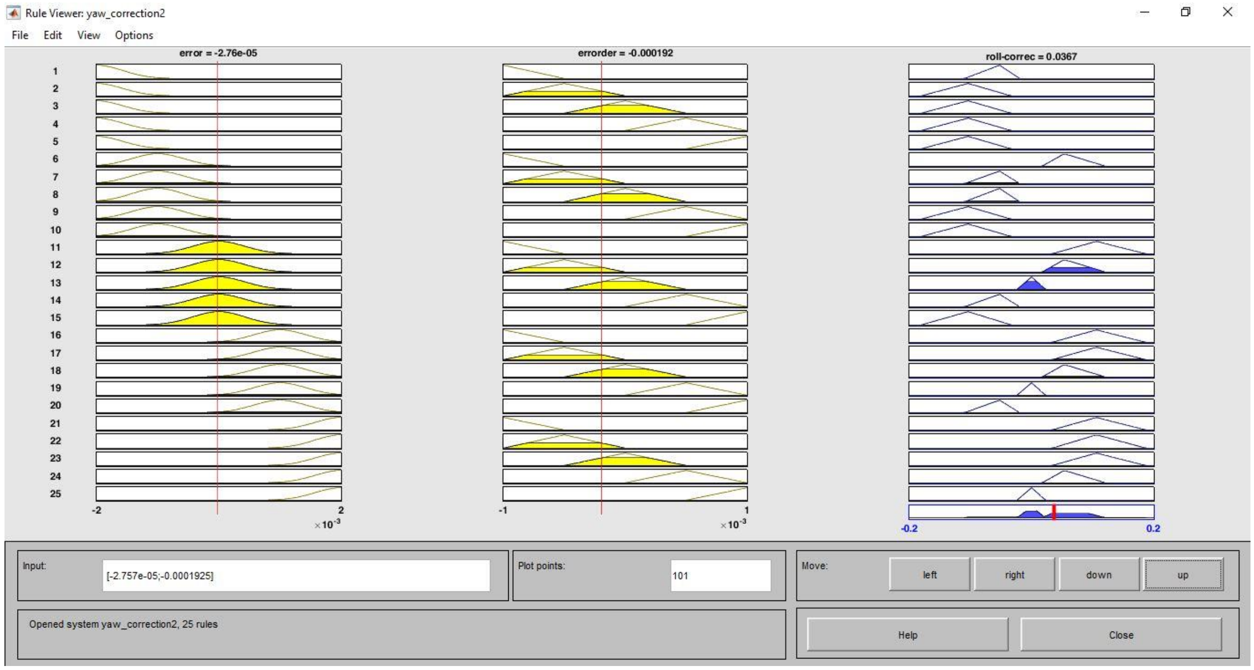


Figure 19: Rule viewer of the FLC on yaw correction

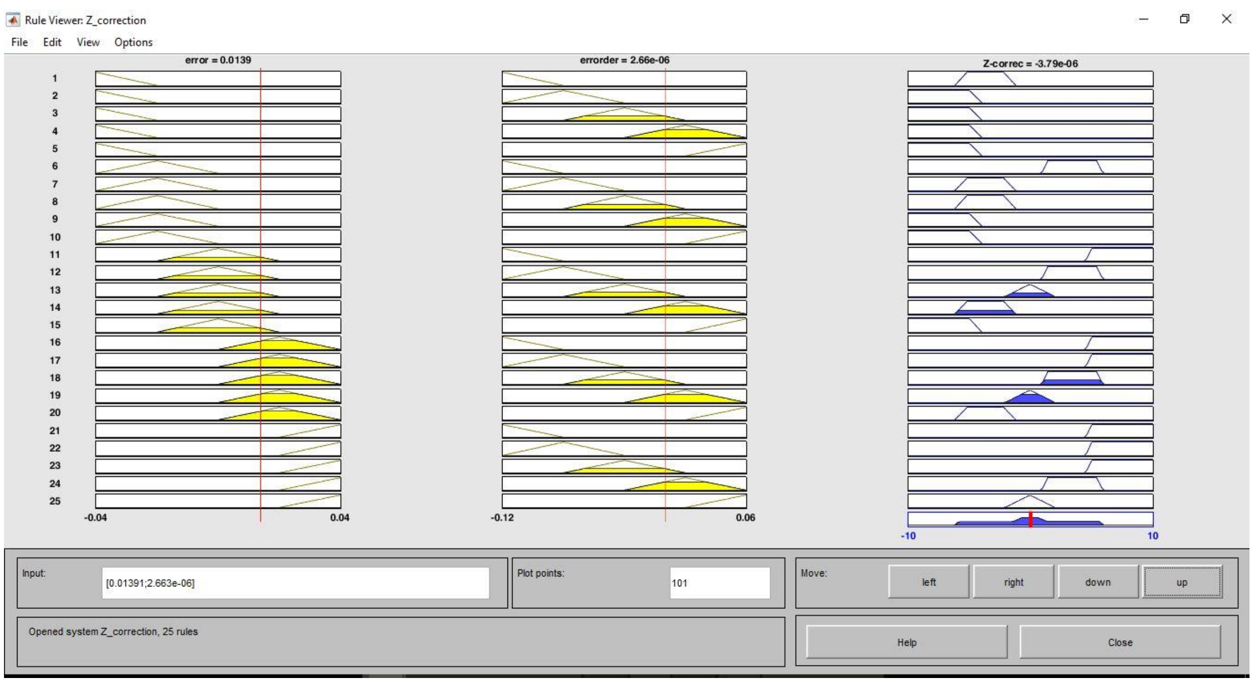


Figure 20: Rule viewer of the FLC on Z correction

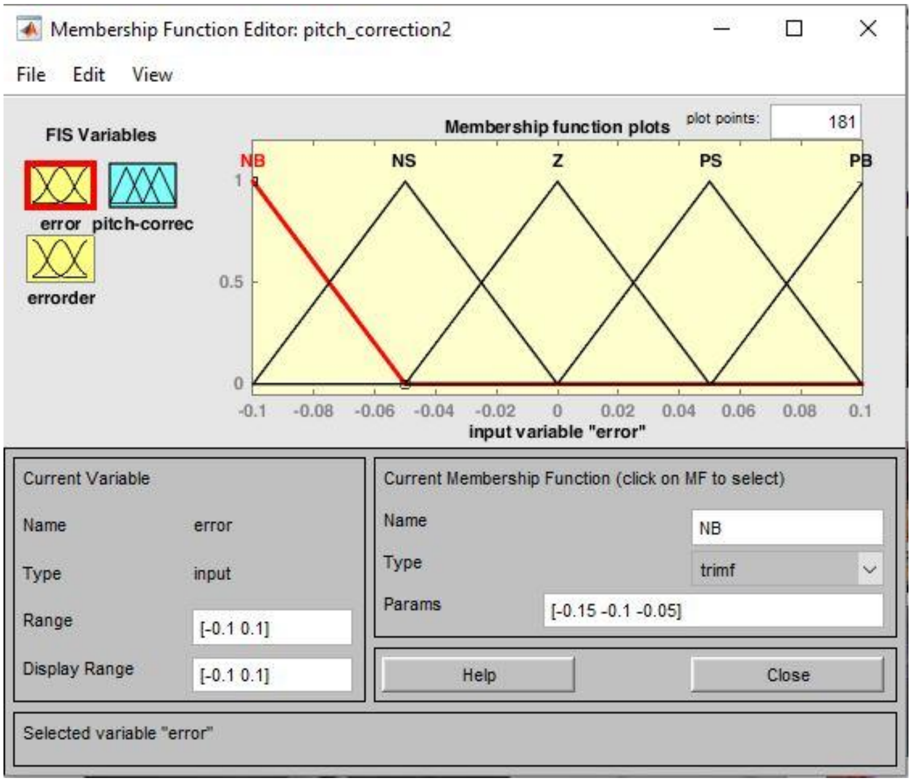


Figure 21: Input-1 of the FLC for pitch correction with 5 MF

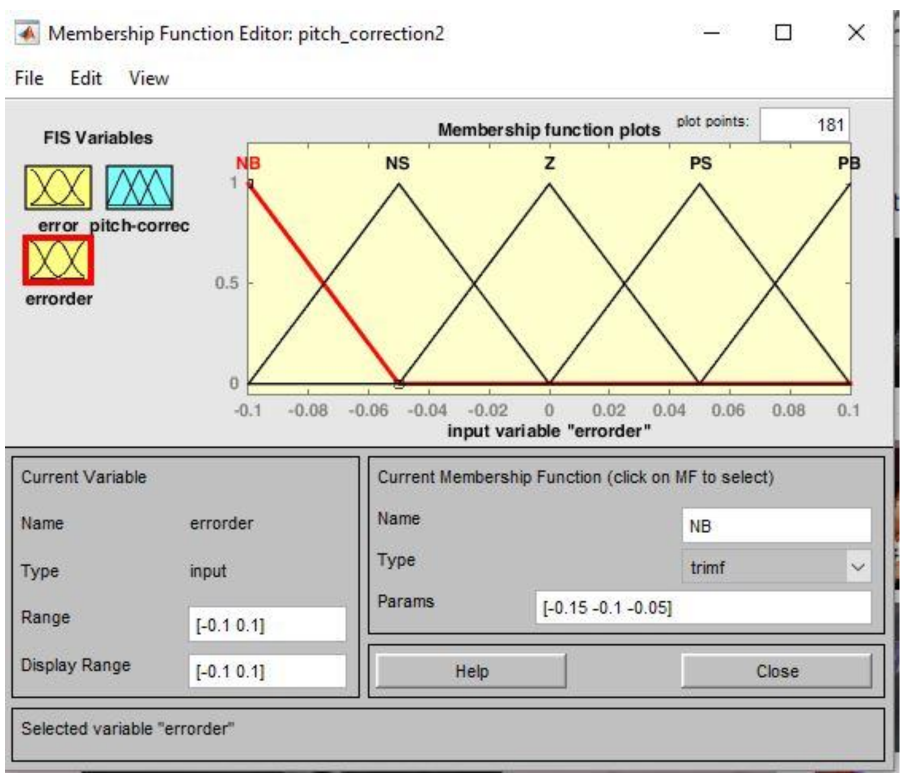


Figure 22: Input-2 of the FLC for pitch correction with 5 MF

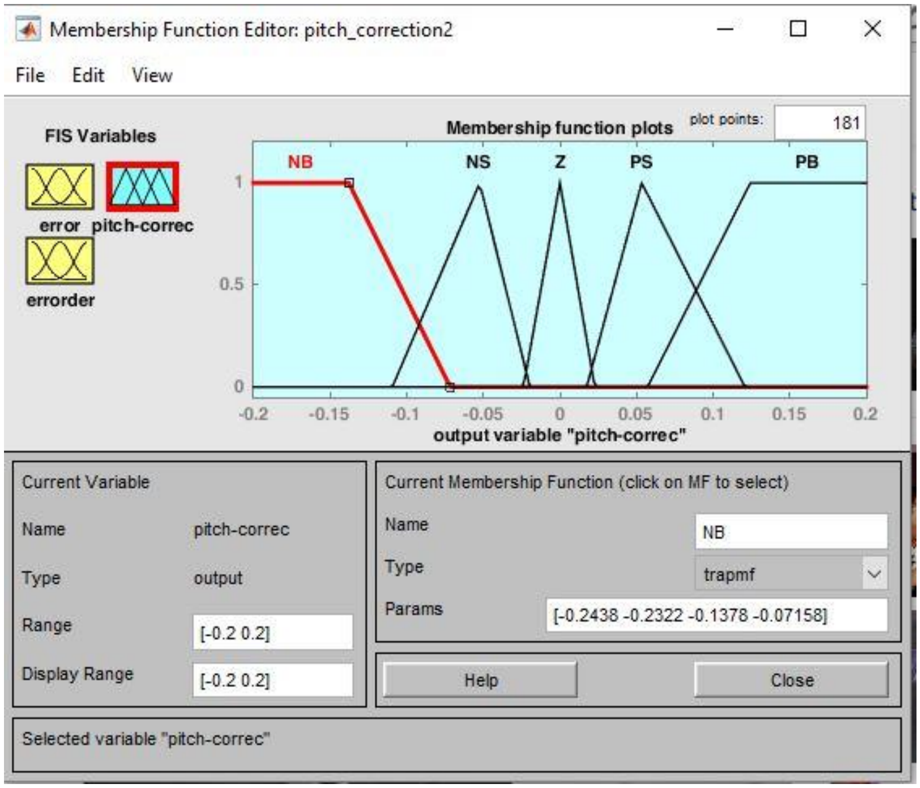


Figure 23: Output of the FLC for pitch correction with 5 MF

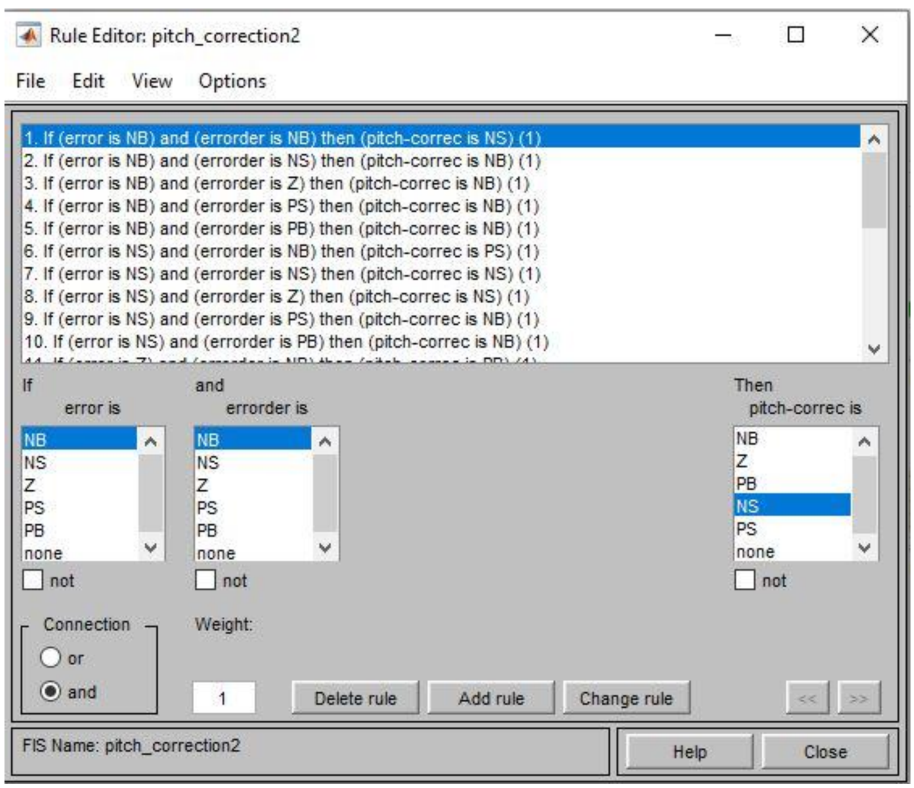


Figure 24: Rules of the FLC for pitch correction with 25 rules

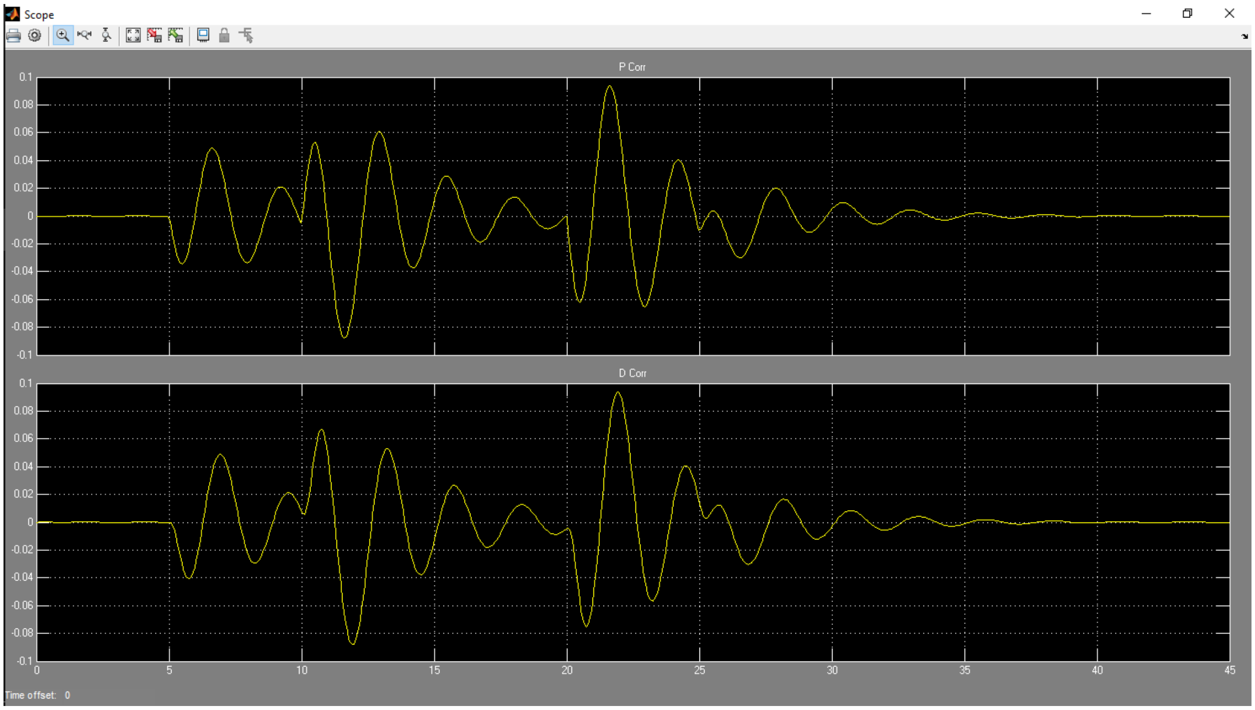


Figure 25: Roll Correction range from PID consisting of error and error_derivative

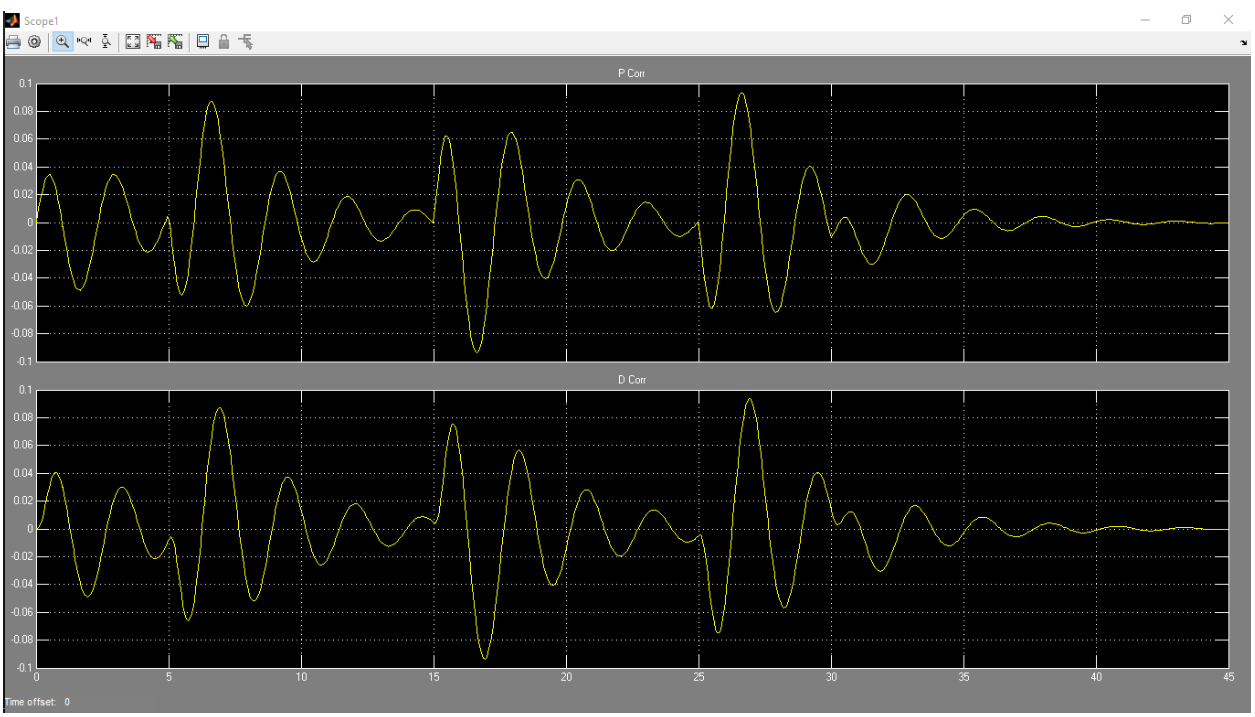


Figure 26: Pitch Correction range from PID consisting of error and error_derivative

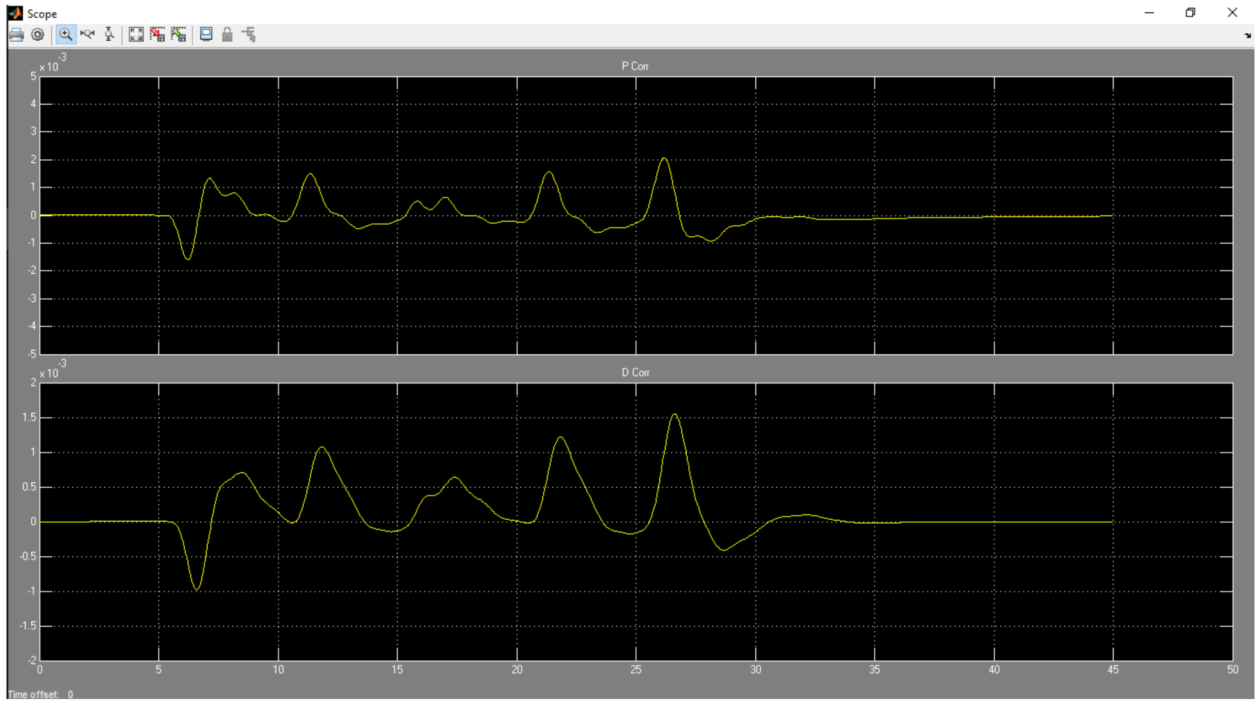


Figure 27: Yaw Correction range from PID consisting of error and error_derivative

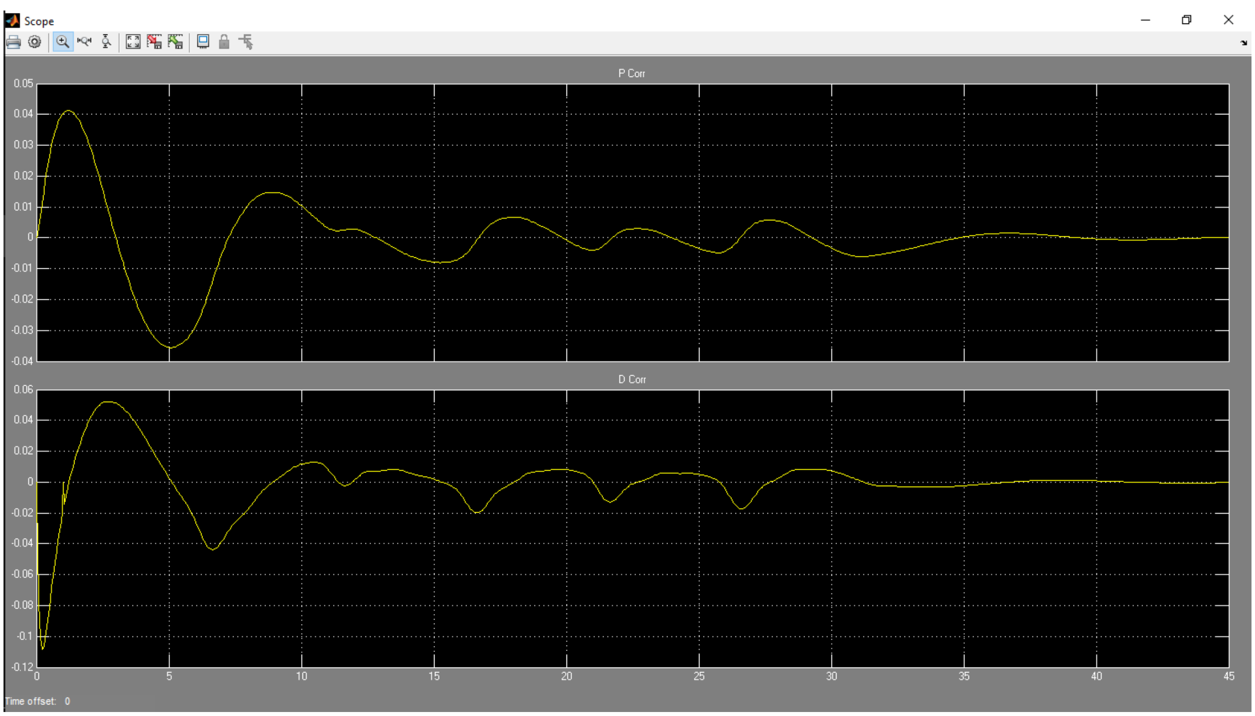


Figure 28: Z Correction range from PID consisting of error and error_derivative

SIMULATION RESULTS

Here are the simulation results which we got from our Trajectory Tracking Model:

1. **Figure-29 shows the first reference trajectory on which we tested our model. Figure-30 and Figure-31 shows the output of PID controller and Fuzzy Logic Controller respectively. It is quite clear from the figures that Fuzzy controller achieved higher accuracy than PID controller in this case.**
2. **Figure-32 to Figure-35 depicts the output in different views for the above-mentioned reference trajectory for PID Controller.**
3. **Figure-36 to Figure-39 depicts the output in different views for the above-mentioned reference trajectory for fuzzy logic Controller before the tuning of parameters of fuzzy logic blocks.**
4. **Figure-40 to Figure-43 depicts the output in different views for the above-mentioned reference trajectory for fuzzy logic Controller after the tuning of parameters of fuzzy logic blocks. It is quite clear that even a small deviation from optimal values of parameters may lead to high degree of error in trajectory tracking of quadcopter. Therefore, parameters of fuzzy logic blocks need to be tuned carefully.**
5. **Figure-44 to Figure-47 and Figure-48 to Figure-51 depict the output in different views for different reference trajectories for fuzzy logic Controller.**

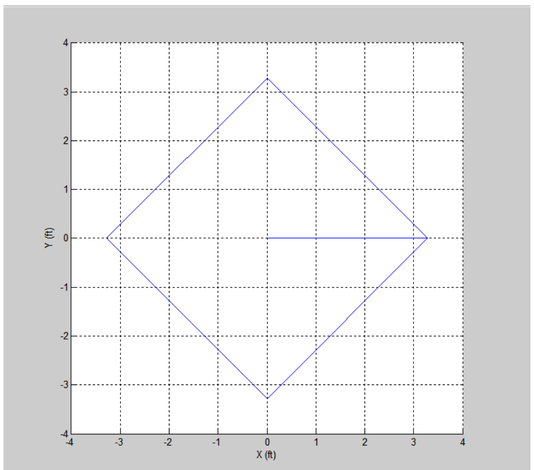


Figure 29: Reference Trajectory

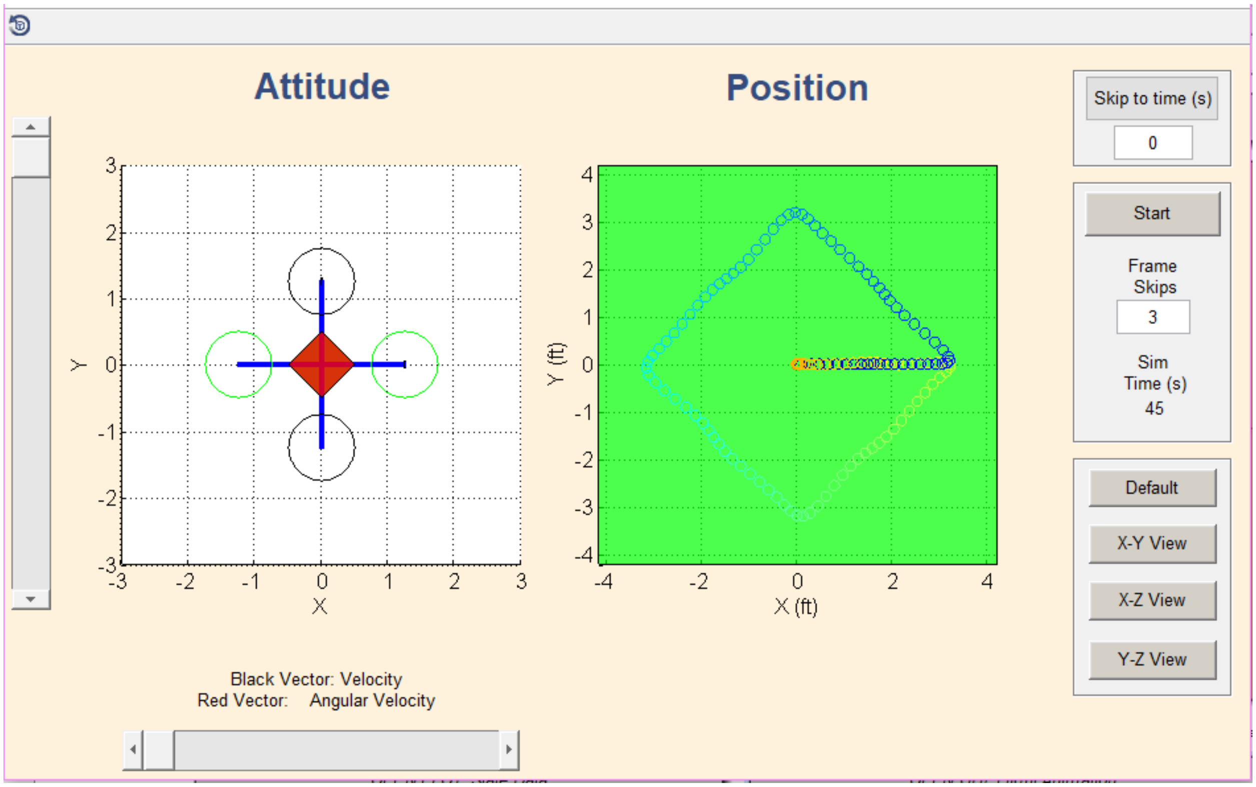


Figure 30: PID Controller Output

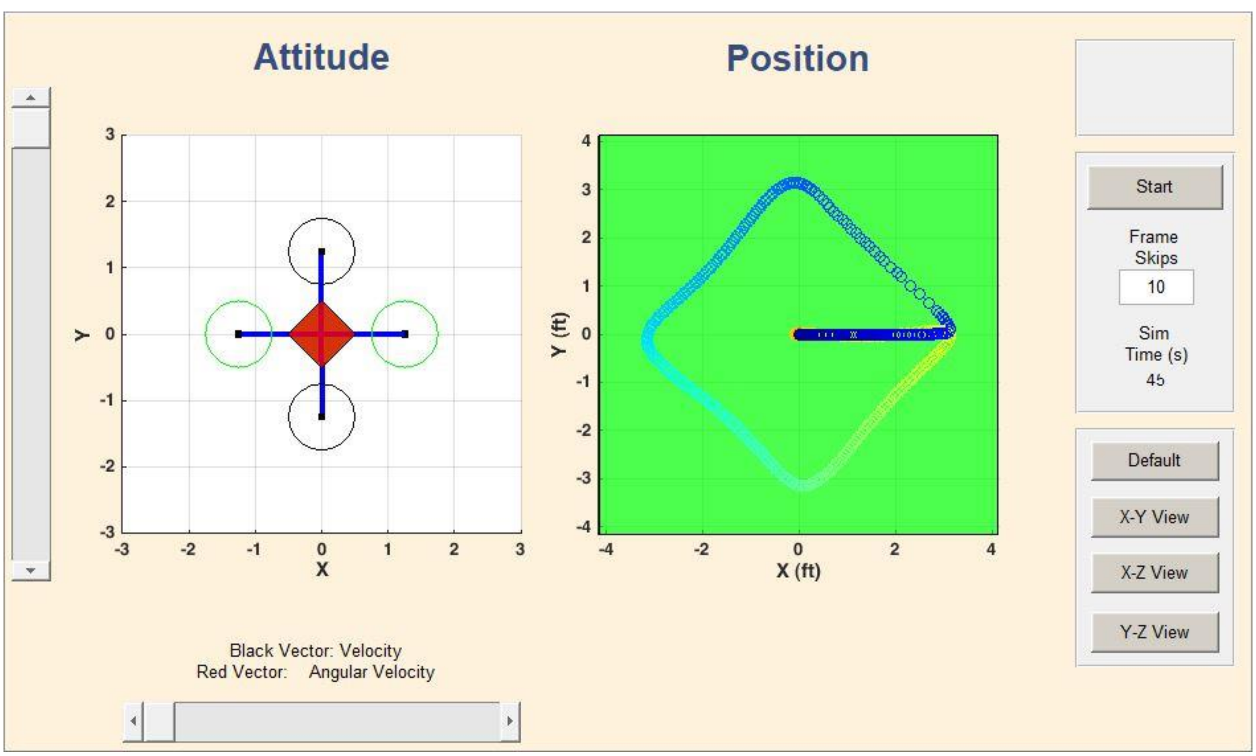


Figure 31: Fuzzy Controller Output

SIMULATION RESULTS WITH PID CONTROLLER

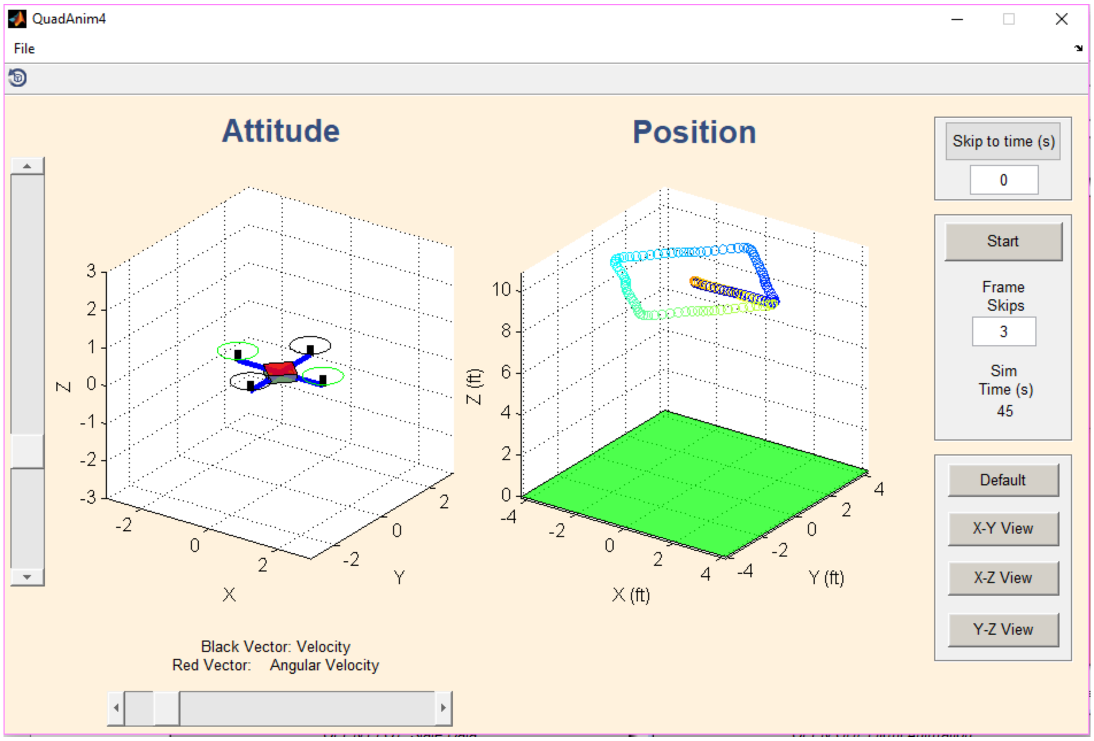


Figure 32: 3- Dimensional View

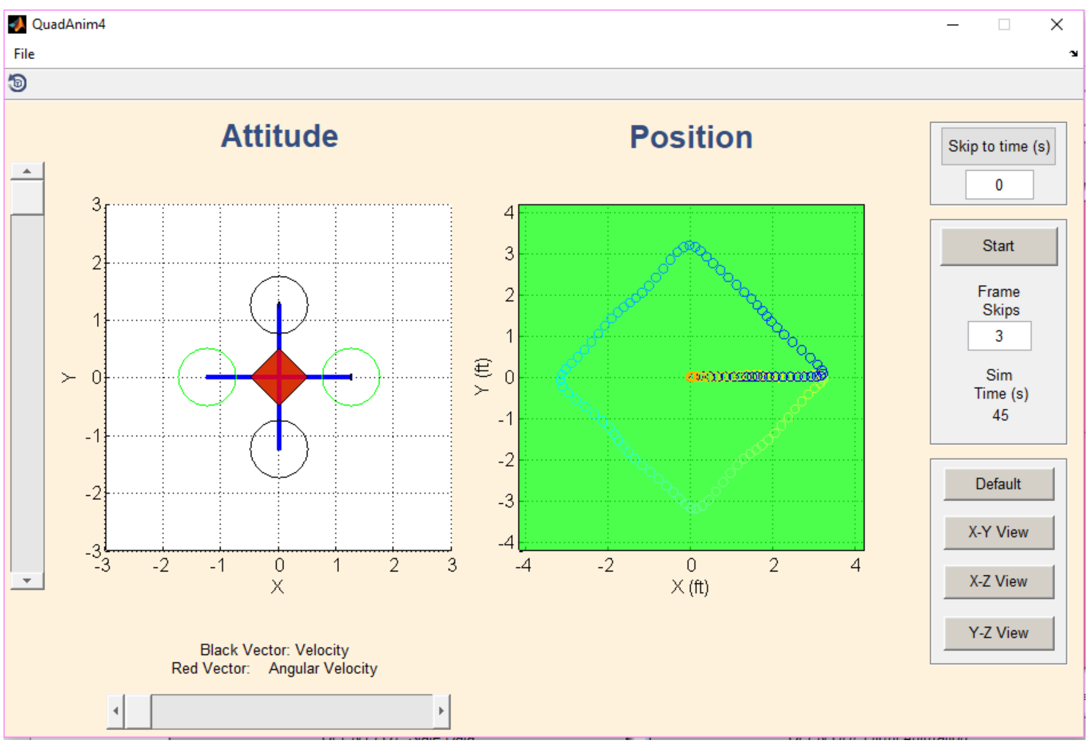


Figure 33: X-Y View

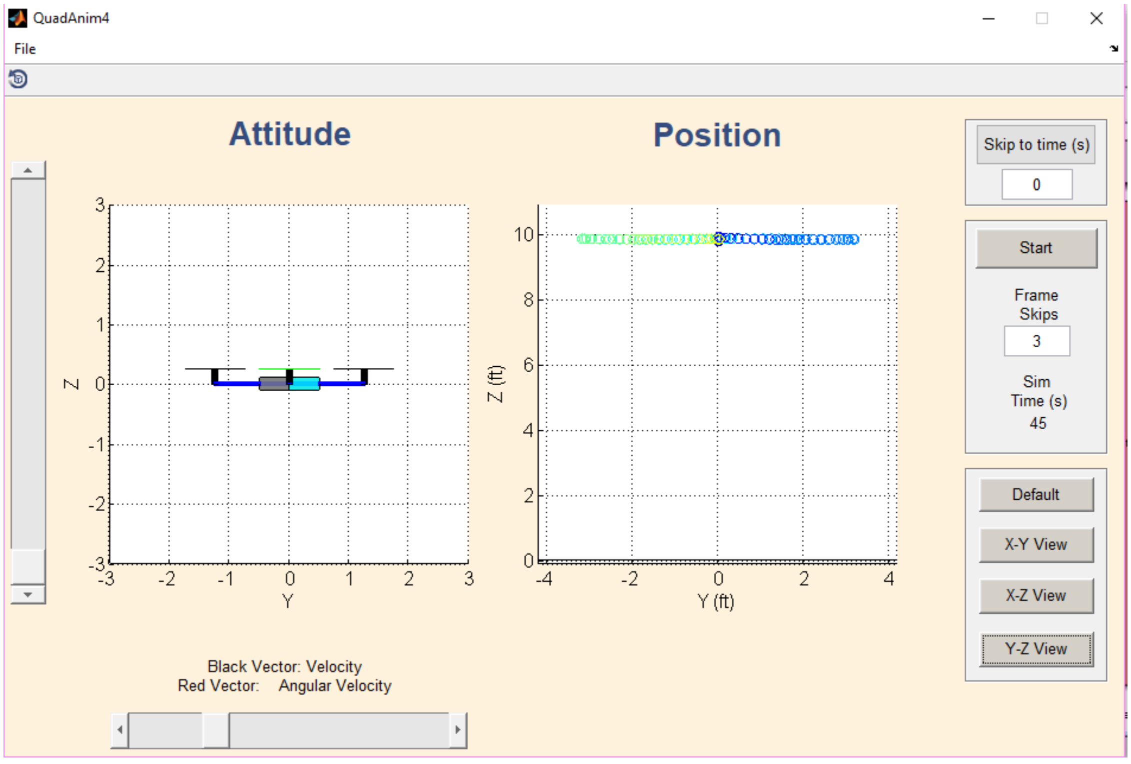


Figure 34: Y-Z View

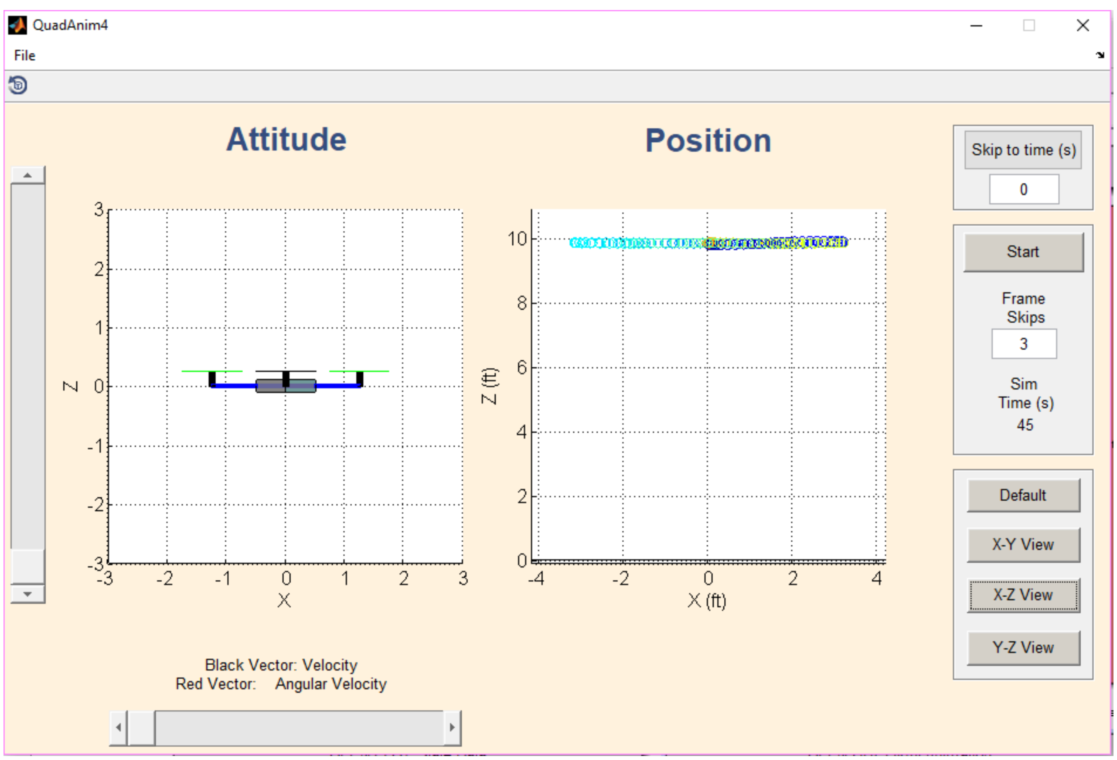


Figure 35: X-Z View

SIMULATION RESULTS WITH FUZZY CONTROLLER (BEFORE TUNING)

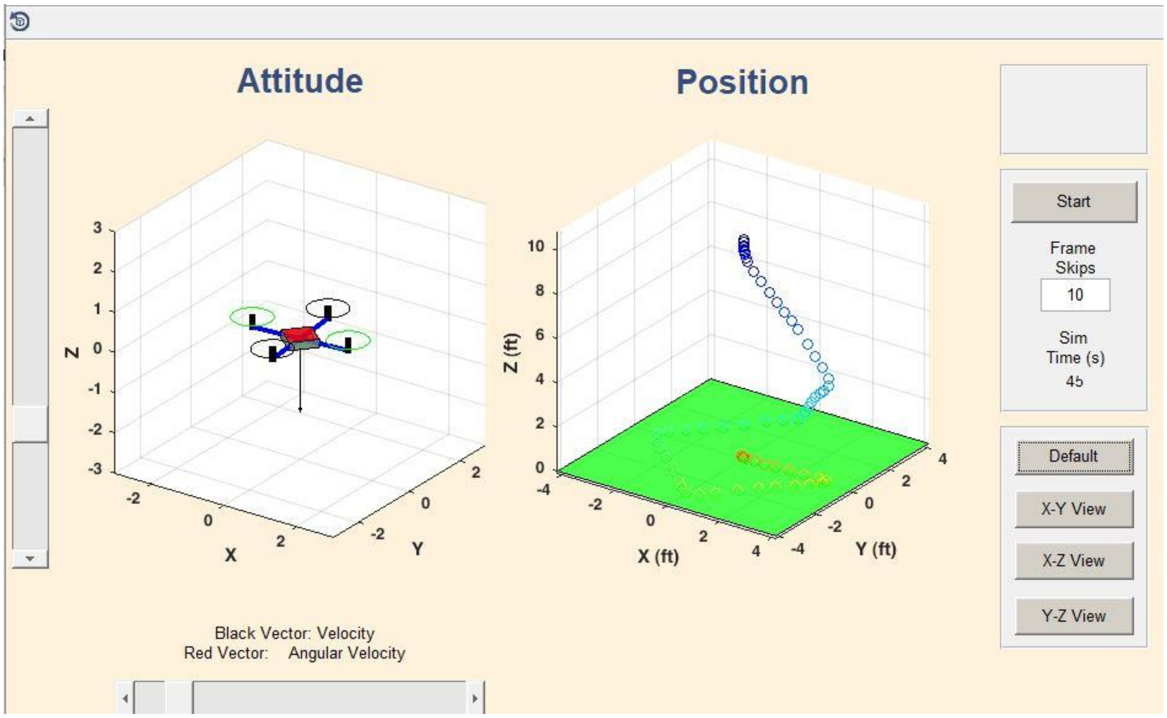


Figure 36: 3- Dimensional View

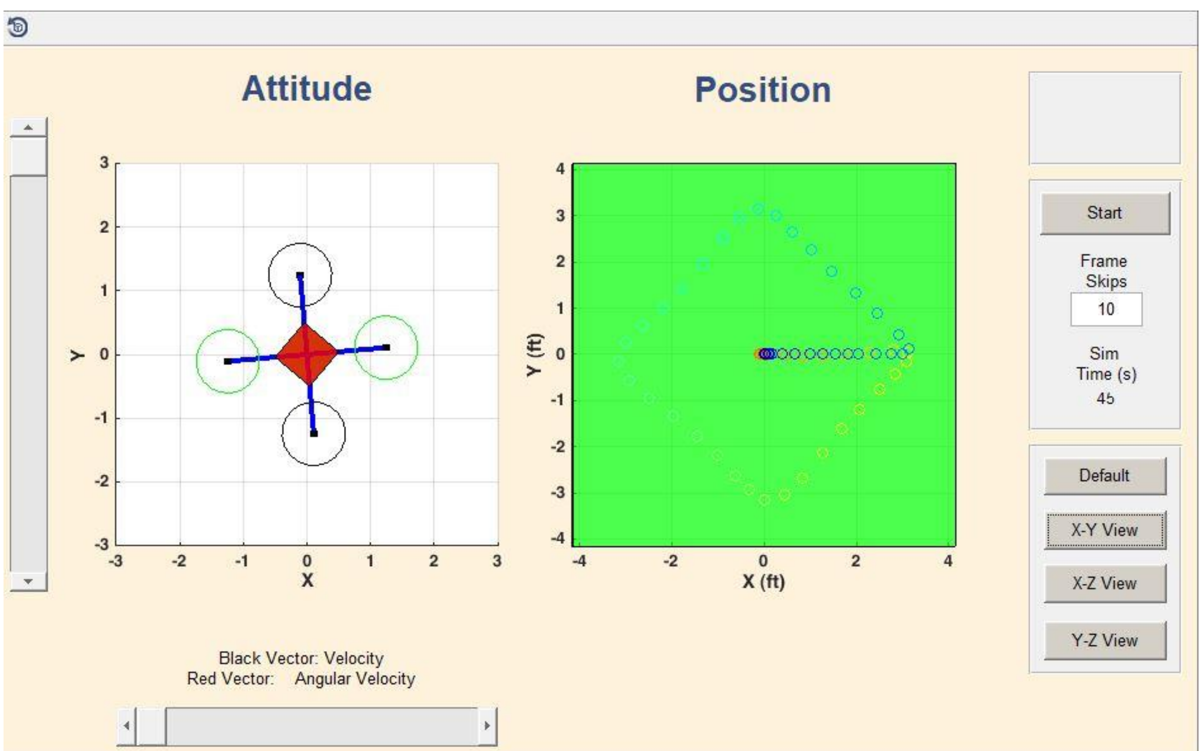


Figure 37: X-Y View

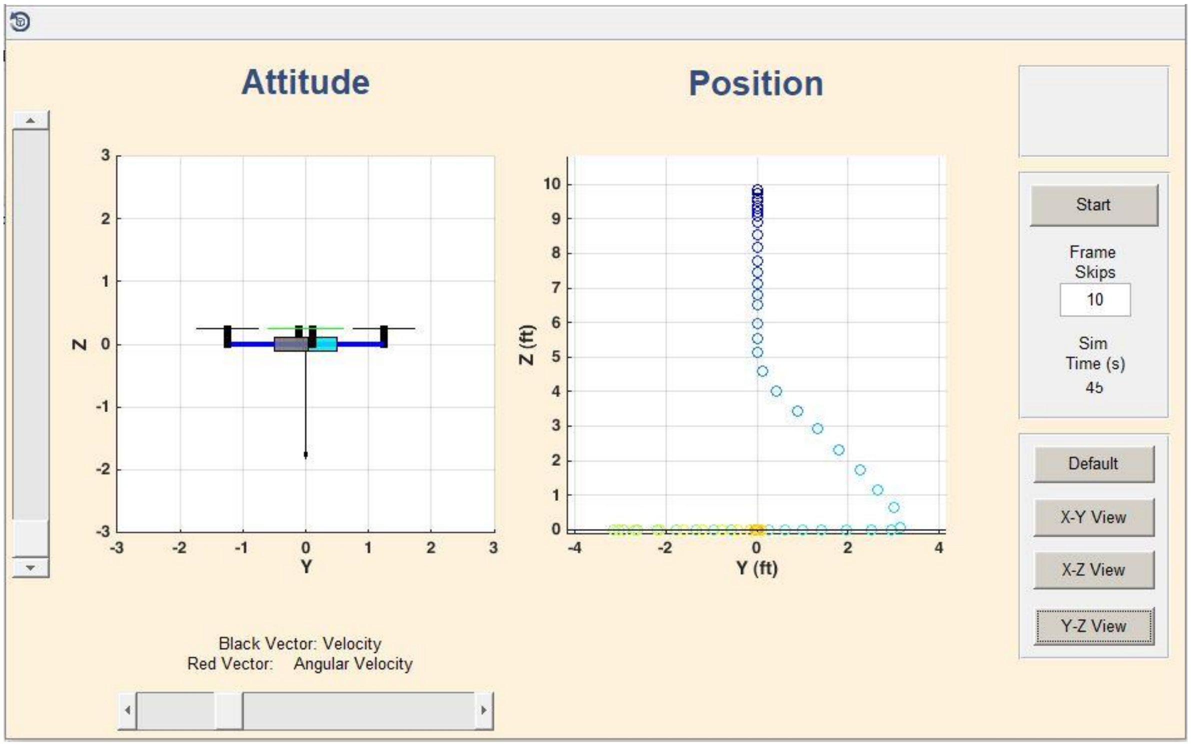


Figure 38: Y-Z View

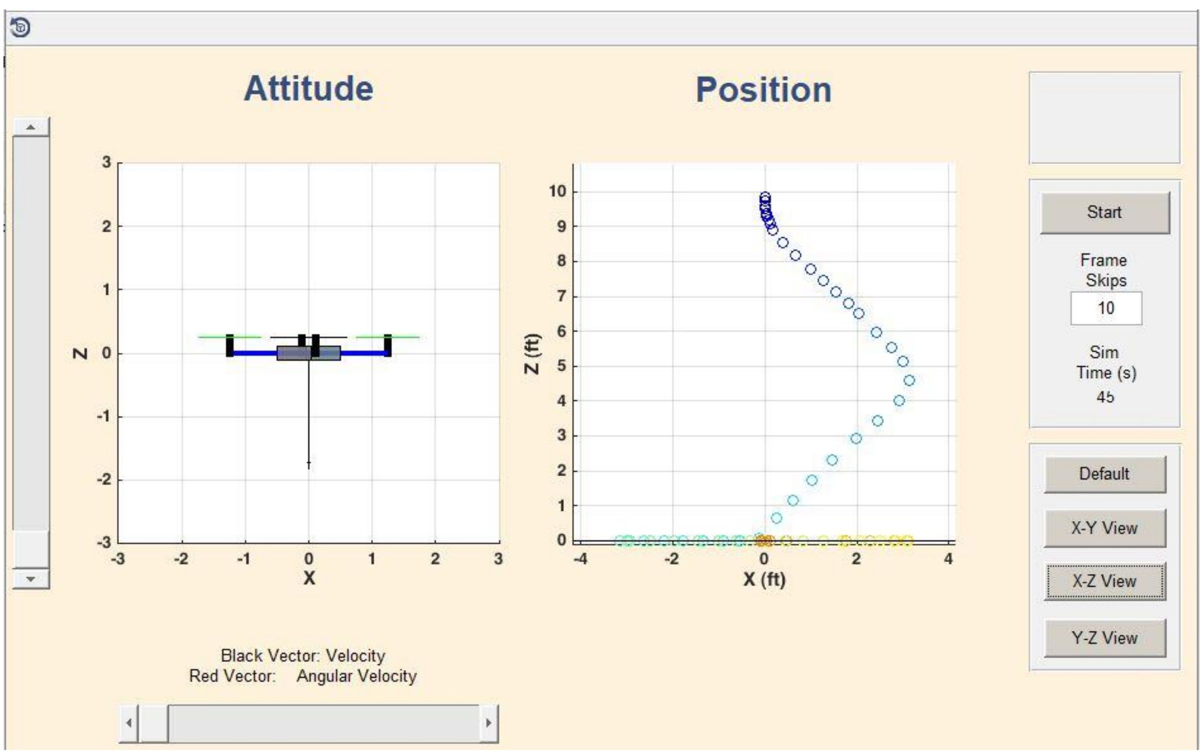


Figure 39: X-Z View

SIMULATION RESULTS WITH FUZZY CONTROLLER - 1

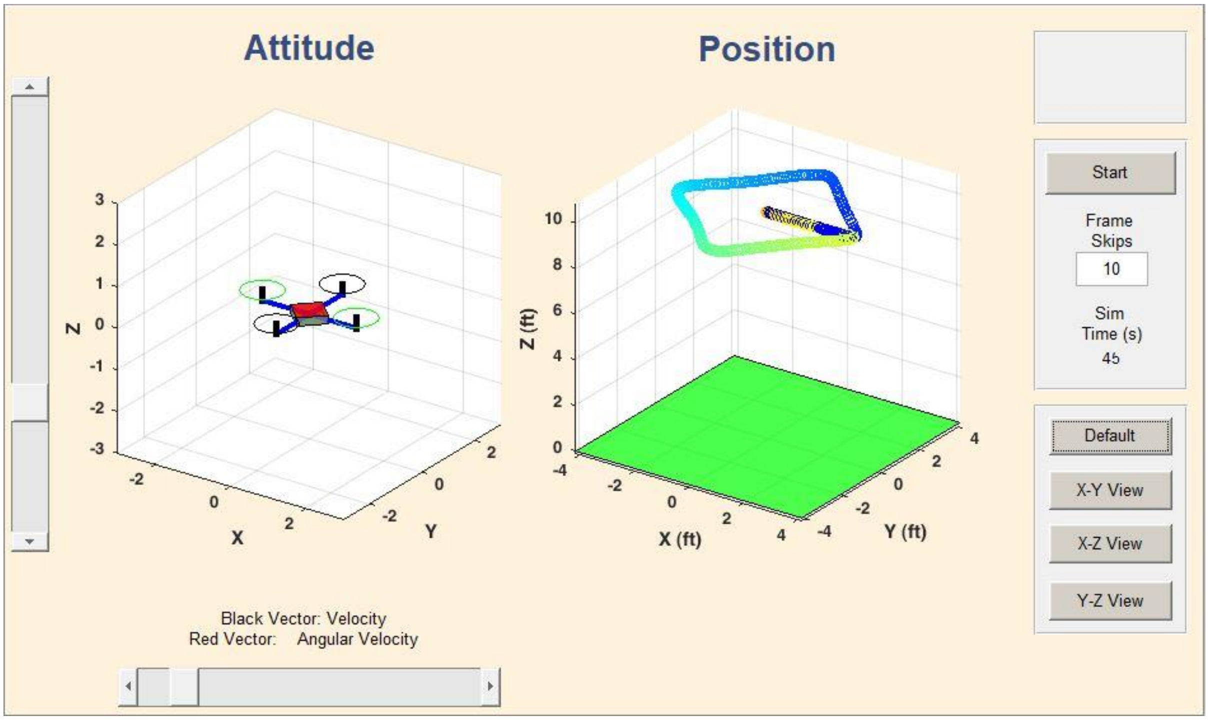


Figure 40: 3- Dimensional View

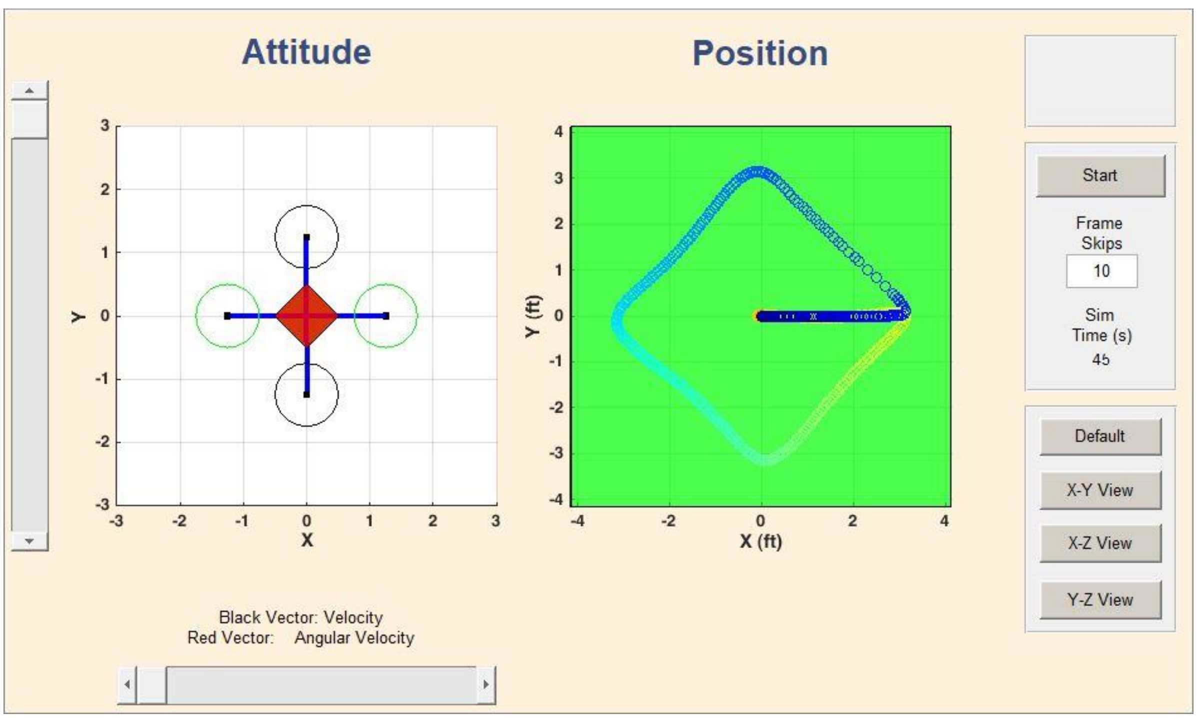


Figure 41: X-Y View

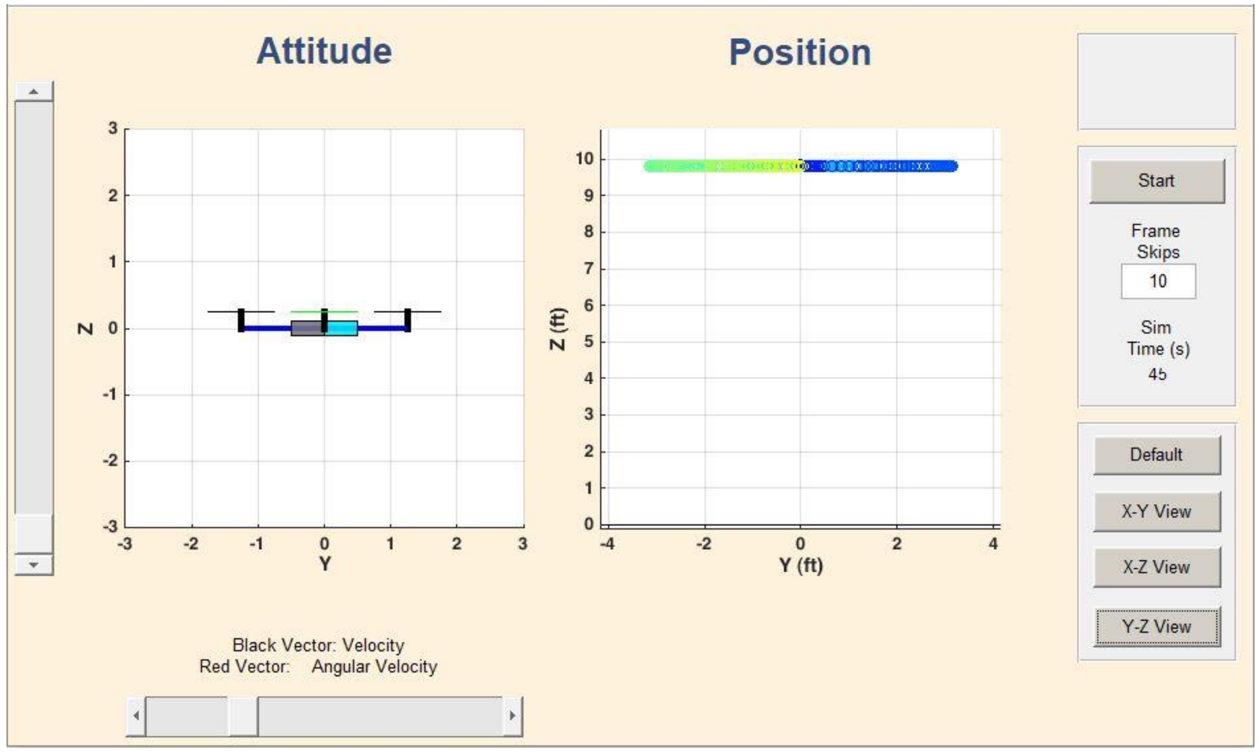


Figure 42: Y-Z View

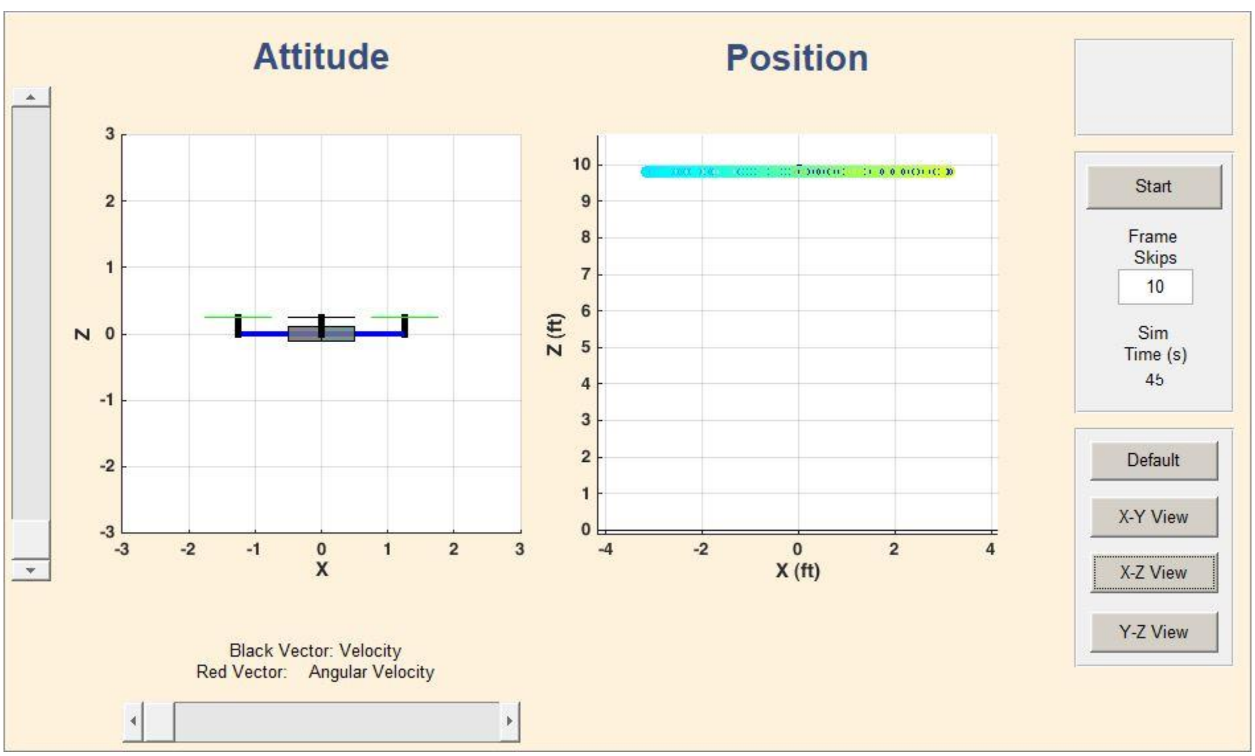


Figure 43: X-Z View

SIMULATION RESULTS WITH FUZZY CONTROLLER - 2

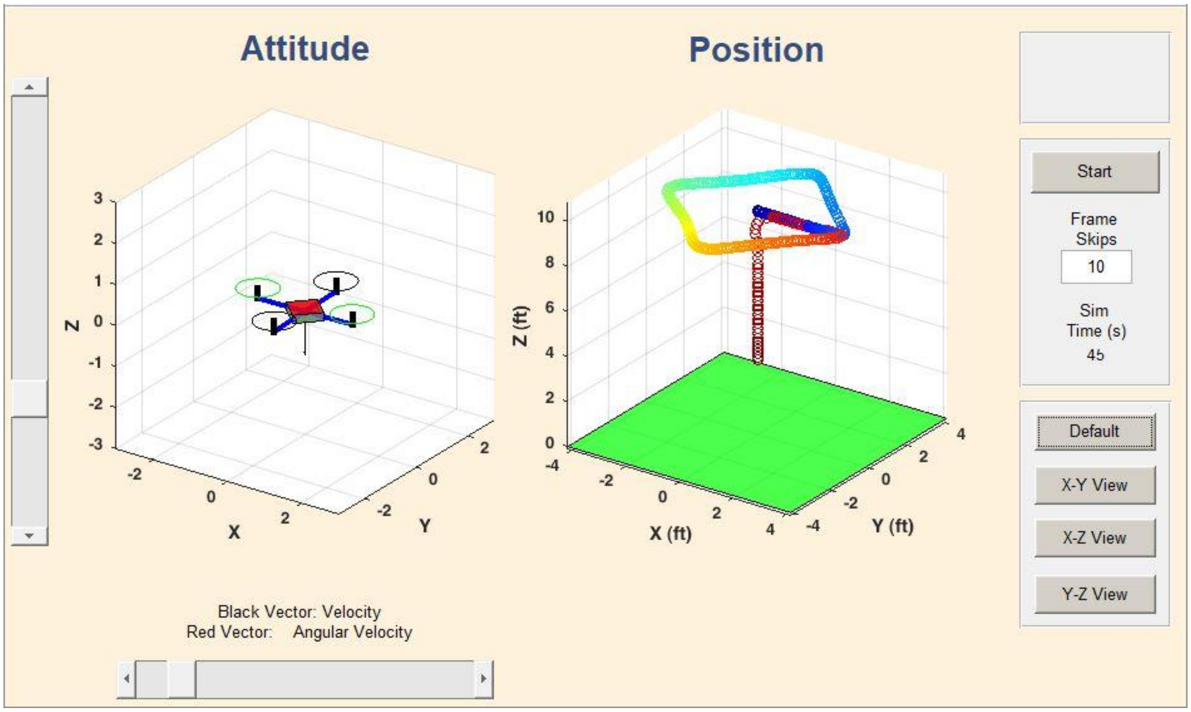


Figure 44: 3- Dimensional View

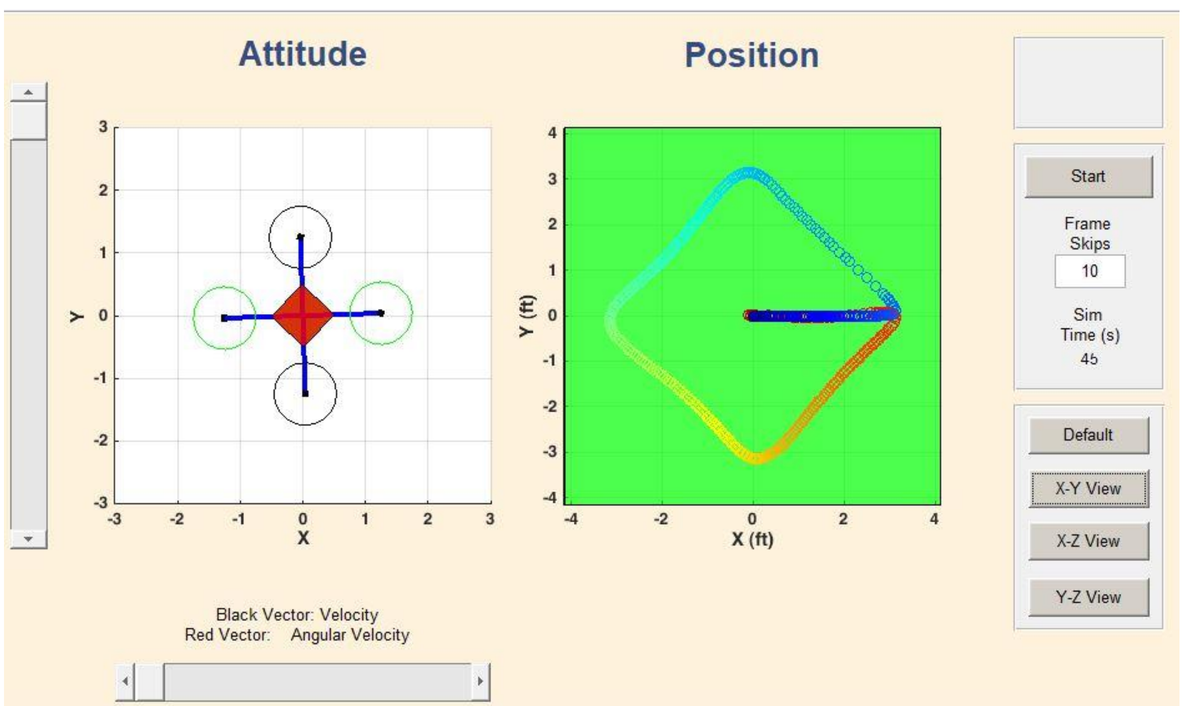


Figure 45: X-Y View

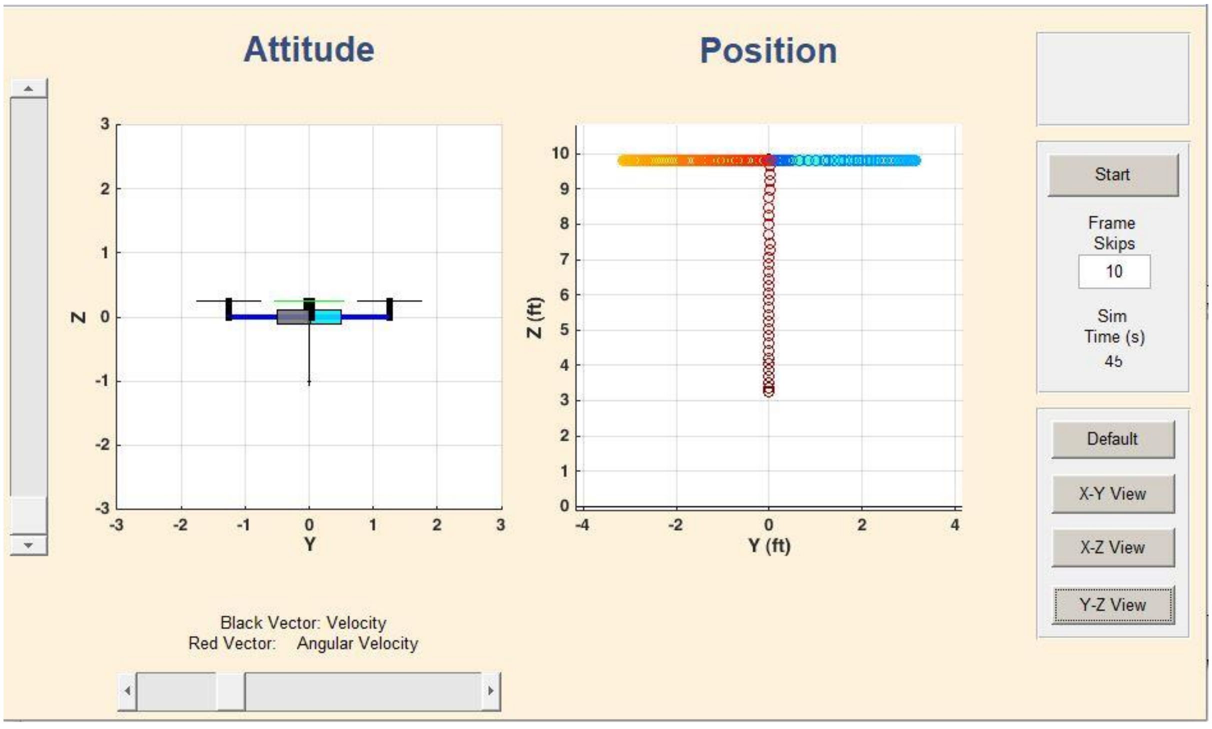


Figure 46: Y-Z View

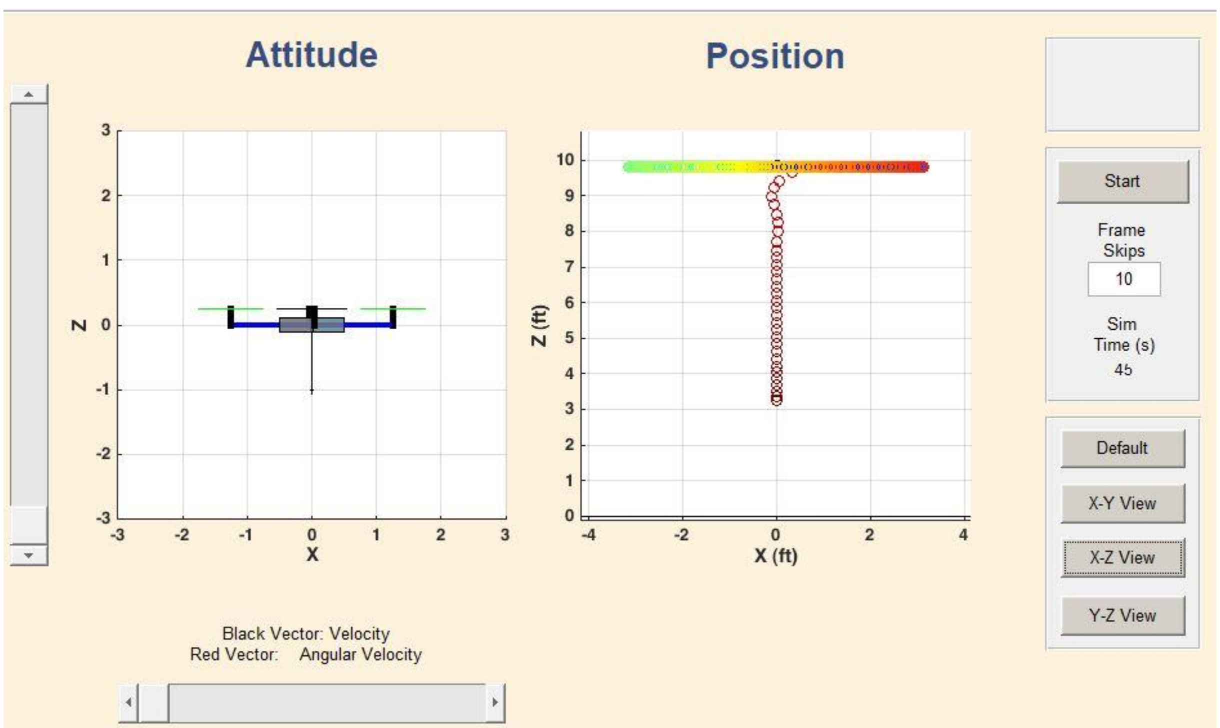


Figure 47: X-Z View

SIMULATION RESULTS WITH FUZZY CONTROLLER - 3

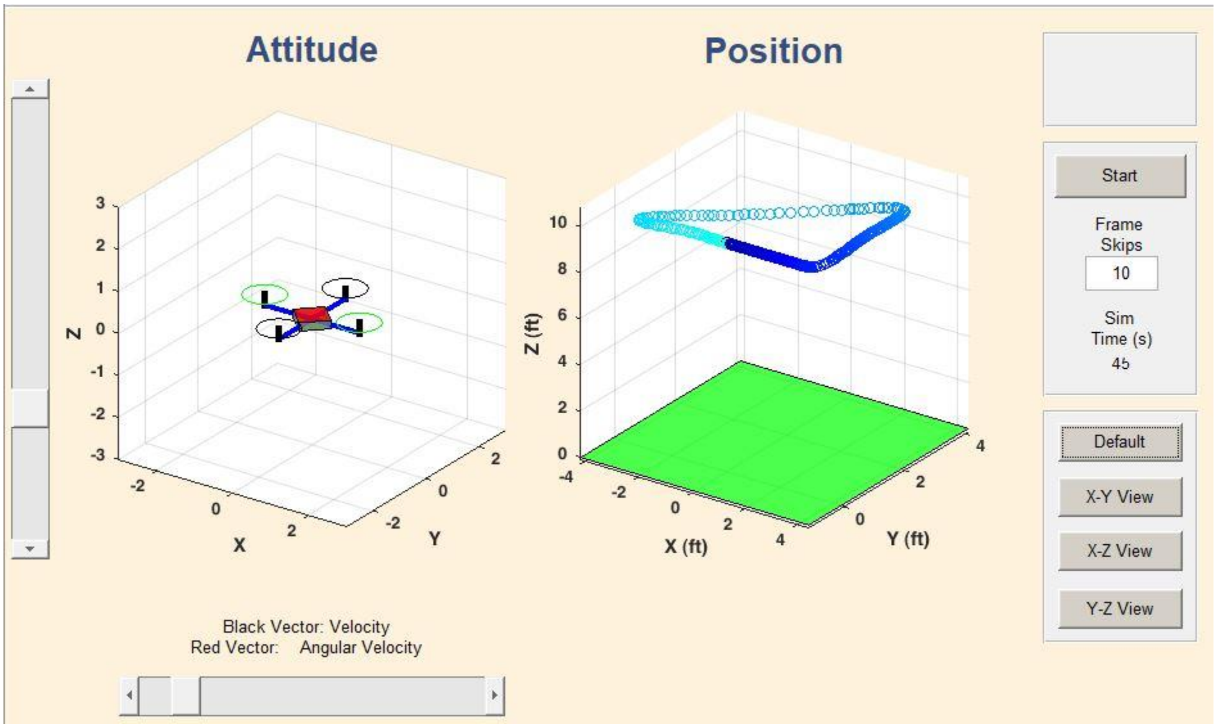


Figure 48: 3- Dimensional View

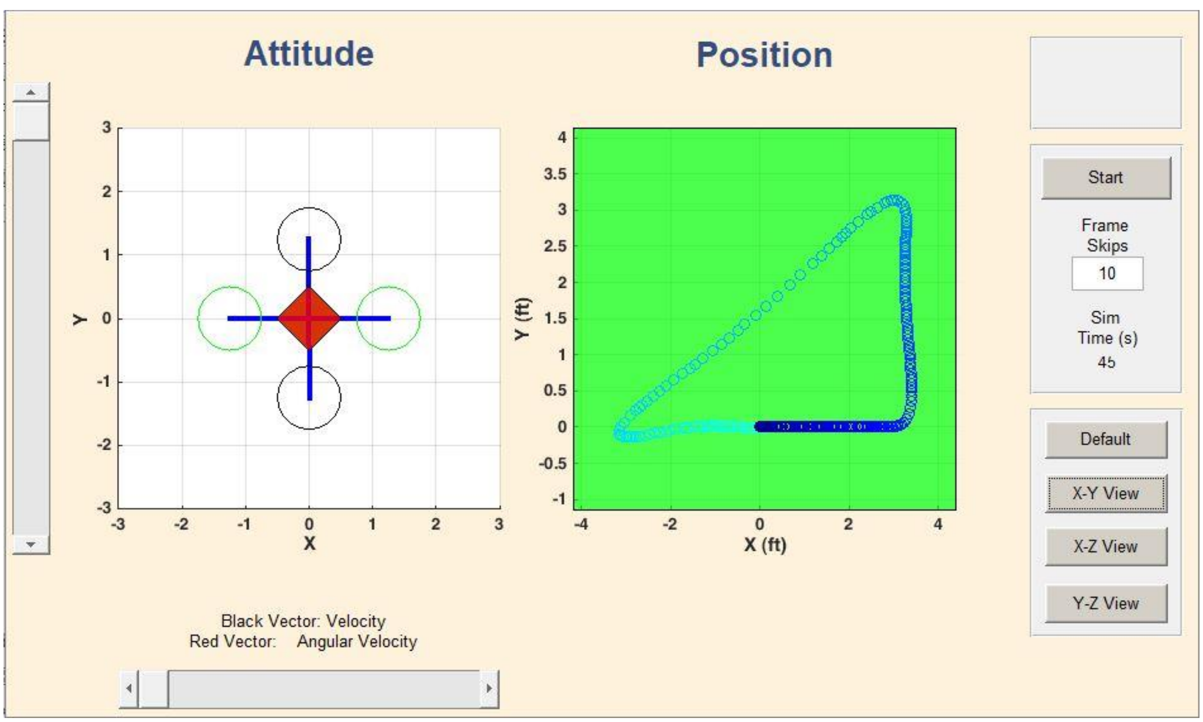


Figure 49: X-Y View

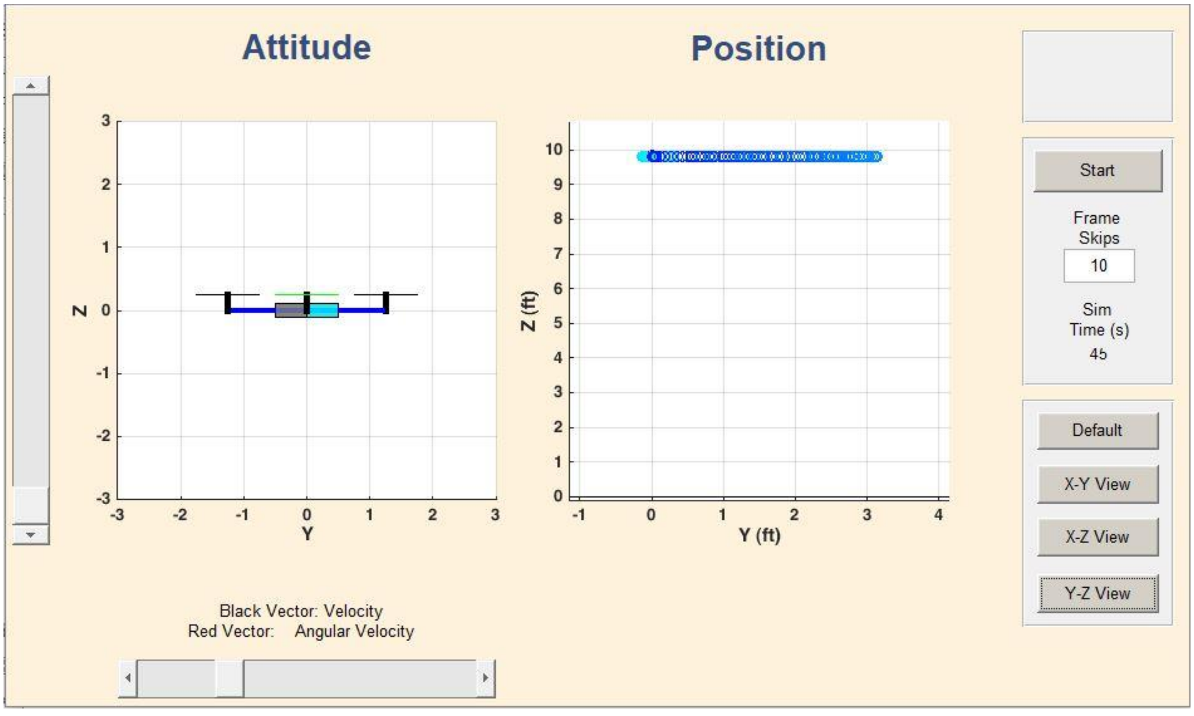


Figure 50: Y-Z View

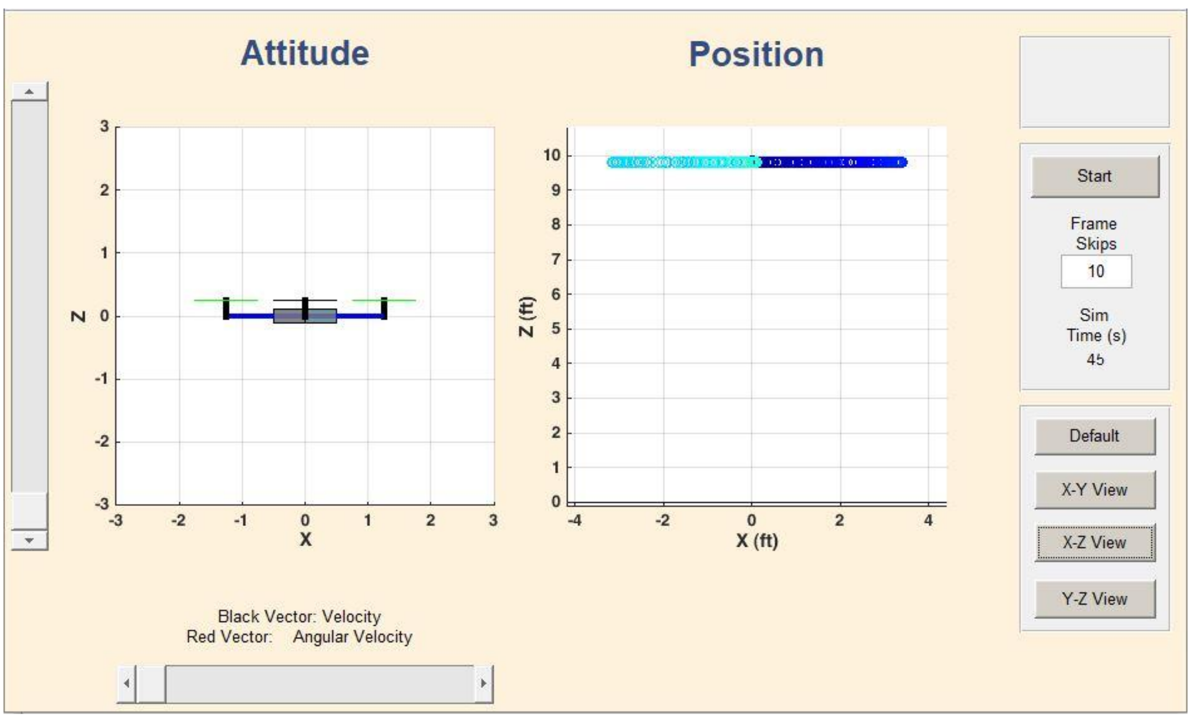


Figure 51: X-Z View

EXECUTION PLAN

- ~~**Stage 1 (February 2018)**~~
    - **Study about Intelligent Control System Techniques and Trajectory Tracking Problem**
    - **Study of Quadcopter Dynamic Model**
    - **Gathering information and solidifying the project procedure**

- ~~**Stage 2 (March 2018)**~~
    - **Testing of Quadcopter Dynamic Model**
    - **Design of Fuzzy logic controller with an aim to improve the performance of the system**
    - **Simultaneously improving performance using advancements in Fuzzy technology**

- ~~**Stage 3 (Till April 2018)**~~
    - **Simulating architectures to observe the performance of Trajectory Tracking System.**
    - **Analyze the performance of our Trajectory Tracking System in comparison with the current techniques.**
    - **Record our Simulation results and Design architectures in the form of a report or presentation.**

CONCLUSION

The implementation of Intelligent control strategies like fuzzy logic in the design of the control system models like quadcopter allows more flexibility and efficiency from the PID controller. The application of expert knowledge about the behavior is sometimes the only way to deal with complex systems.

In this report, an intelligent control system based on fuzzy logic has been designed and implemented in order to control a quadcopter. This system has some complex dynamics because of the coupling of the different variables that represent the motion which includes its six degree of freedoms.

The results obtained by compiling the code for the model and running the simulation are more accurate with the reference trajectory and thus gives an edge to this application over the PID controller. The control system works with the parameters in the given range with proper tuning, thus not comprising the stability of the quadcopter, precision and the speed.

Due to the inter-dependence of the variables, the tuning of the controller parameters plays an important role in this application. The future work if to be done, can be to improve and include the disturbances or external drag forces to the state space equations which will be helpful to prove the controller in the real environment. Problems such as noise, uncertainty from the sensors, etc., will help to show the robustness and efficiency of this strategy.

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