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Fuzzy Scheduling Control System Design for Quadrotor

MSc Thesis

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Approval

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Declaration

I declare that all work, information, documents, analysis and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully listed referenced and cited them in a proper way and referenced information and data that are not original to this thesis.

Sanan Abizada

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Sanan Abizada

Abstract

Fuzzy Scheduling Control System Design for Quadrotor

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Quadrotor unmanned aerial vehicle is a flying transporter machine that has a high order of nonlinearity and external disturbances have an effect that makes it highly sensitive. It is challenging to control these vehicles. This thesis proposes a controller design of a fuzzy scheduling controller for the purpose of quadrotor control. To solve the stated problem the state-of-the-art control methods used for the control of UAVs are presented. It was shown that UAV dynamics are high order nonlinear and sensitive to external disturbances. One efficient method for control of UAV is the use of fuzzy logic. The kinematics and dynamics of UAVs are presented. By using a set of equations that brings a dynamic model and simulator, we achieve only an acceptable simulator and the dynamic model of a complex mathematical model. Quadrotor kinematics is presented in two coordinate systems. These are the body-fixed axis and earth-fixed axis. The relation matrices between these two coordinate systems are presented. Afterward, using the Newton-Euler method quadrotor dynamic model is obtained. It was found that the basic controlled variables of the quadrotor are thrust, yaw, pitch, and roll which are altitude (thrust) and attitude(yaw, pitch, roll) variables of the quadrotor. At first, the design of a traditional PID control system is performed for each variable. Simulation has been done and transient response characteristics are obtained for PID control systems. Using the presented structure, we obtained the performance result of the fuzzy control system is derived. It is called the transient response characteristic of controlled parameters. The structure of the control system is proposed. Using proposed structure and dynamic models of attitude and altitude variables the design of a fuzzy scheduling control system was performed. To prove the efficiency of the designed system comparative results of transient response characteristics of PID and fuzzy scheduling control were derived. The obtained simulation results demonstrate and prove how the fuzzy scheduling controller is efficient when we control quadrotor in real-time control.

Keywords: Quadrotor, Dynamic Modelling, Kinematics, Fuzzy Controller

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LIST OF ABBREVIATIONS

AI: Artificial Intelligence

ANN: Artificial Neural Network

UAV: Unmanned Areal vehicle

CHAPTER I

Introduction

Robots and autonomous objects have always attracted the attention of humankind to research and development. We have made great progress in the development of UAVs (Unmanned Aerial vehicles). This study was started in 2021 and became a thesis in the same year. The world of robots has expanded into the 21st century. The thesis began in 2021, at a time when the robot community was showing a growing interest in the development of the Unmanned Aerial Vehicle (UAV). An area where the need to regulate research and development raises interest in this area. The need for new and better control solutions in the UAV environment is encouraging and challenging. The role of UAVs in our lives is increasing. Investment in UAV projects is supported due to the wide range of application areas in both civilian and military areas. During that time, the Robotics Laboratory did extensive research on both air and ground vehicles and gained a wealth of knowledge. Many studies such as finding ways, avoid obstacles have been done.

Technological and industrial advances have given us the Inclusive Measurement Unit (IMU) which is a small integrated system. It contains a magnetic sensor gyroscope, accelerometer, and magnetometer. The cost of programs like IMU is leading the public robotic market to expand. The integrated sensors encourage researchers to use Micro-Electro-Mechanical Systems (MEMS). IMU is small in size and its low cost leads to certain limitations such as low accuracy due to noise and poor data processing compared to conventional sensors. Small motors, electrical objects lead us to select UAVs. On the other hand, the control part is still a challenge. As a result, a VTOL (departure and vertical aircraft) called Quadrotor has been selected. It has an inspiring research environment which is a problem of control and attractive power. A quadrotor is a UAV with four motors mounted on the opposite configuration. A quadrotor is also called a helicopter. Two pairs opposite four motors rotated clockwise. The other two pairs rotate to one side in relation to the other two motors. The main purpose of this is to establish the torque balance. Boundaries we need to control roll, pitch, yaw, and throttle (up-thrust force). By controlling these parameters we achieve quadrotor control. The quadrotor has plenty of space to use both residential and military facilities. Aerial photography, mapping, and integration, power and location surveys, space forecasts, fire detection, control, traffic monitoring, natural disaster surveys, border surveys for import and export.

Research Problem

The variation of motor speeds leads to control of the quadrotor. The parameters we need to control are roll, pitch, yaw, and throttle(up-thrust force). By controlling these parameters we achieve the quadrotor control. The underplay design and dynamics of the quadrotor make the control of the quadrotor complex. External disturbances have an effect on quadrotor motion. Several kinds of research have been approached on challenging the control of quadrotors. The quadrotor dynamics have non-linear nature and consist of complexity. That leads the task to become challenging.

Vehicle speed variation leads to quadrotor control. Boundaries that we need to control are roll, pitch, yaw, and throttle (up-thrust force). We acquire the control of the quadrotor by controlling these variables. The quadrotor kinematics and dynamics enable control of the quadrotor complex. External disturbances affect the movement of the quadrotor. Several types of research have been reported to challenge quadrotor control. The quadrotor power is unbalanced and contains complexity. That leads to a challenge.

Significance of the Study

AI is developed in many different fields and also robotics and vehicle control. AI is used where humans and its performance are insufficient. Applications of AI reached extensive areas and significant application effects. It leads to advance in control techniques. In this study, it will be clarified how fuzzy scheduling technique is demonstrated on quadrotor attitude and altitude control and This study will show how presented control technique helped to optimize the control of quadrotor and leading to the advancement of new algorithms and methods. AI is a continuously advancing field. This study will state fuzzy scheduling controlled quadrotor.

Limitations

This study has resource limitations. It is limited to use applications of different control techniques in EEE (in articles and papers) which are available online and free to access.

Motivation

Flying vehicles are fascinating for research. It is very motivating to see the result of your research in flying robots. Aerial vehicles have more control areas and fewer limits compared to low-traffic robots. It leads to the acquisition of additional research space and control mechanisms that can be demonstrated in ground-based robots. UAV technological advancements help technology to spread in a variety of sectors. The Internal Measurement Unit (IMU); contains a magnetic sensor gyroscope, accelerometer, and magnetometer. Low-cost IMU and integrated sensors lead researchers to work in the UAV area. Quadrotor UAVs used in aerial photography of mapping and new coverage, transportation of loads, an inspection of power lines, atmospheric analysis of weather forecasts, traffic monitoring, crop monitoring, border inspection of imports and exports, fire detection and control, rescue operations, natural disasters, broadcasting. Therefore, the controller design for the quadrotor is a challenging task.

The state of the problem

Taking into account the actuality of increasing efficiency of the control system of quadrotors, the main idea of the thesis is to construct the design and propose the fuzzy scheduling control of quadrotors. To Design the stated control system the following have been done in the thesis.

- Using body-fixed axis and earth-fixed axis the kinematics of quadrotor is derived.
- Using the Newton-Euler method quadrotor dynamic model is obtained. The models are designated for attitude and altitude quadrotor control, that is trust, roll, pitch, yaw control parameters.
- the design of a traditional PID control system for each trust, roll, pitch, yew control variable. the design of a fuzzy scheduling control system for each trust, roll, pitch, yew control variable.

CHAPTER II

Literature Review

State of art used control methods for quadrotor

Control of the speed of motors is a complex task so a set of researches published in this century to accomplish the task. These researches presented different algorithms that made for the quadrotor control. These control methods are both up thrust and quadrotor paths.

The paper (Mahonya et al, 2012; Huo et al., 2014) accomplishes the control of the selected UAV which is quadrotor by changing the motor speeds. However, because of the combined complex design configuration, dynamics and unstable nature, control of the quadrotor is a hard task. It is always a task that challenges the ones who work on it. In this thesis, for altitude prediction and translational velocity, accelerometers, magnetometers and gyroscopes are discussed and then camera systems, GPS and motion-capture systems are used for position prediction. A brief overview of the control hierarchy was conversed about. The extension of motion to the forward motion where blade flapping becomes important. Measurement of the attitude and altitude achieved from accelerometers, gyroscopes, and magnetometers which is an estimation, not accurate was used to achieve attitude and translational velocity, and GPS, motion-capture systems. To calculate the position, it used a camera.

The quadrotor is easily affected by external disturbances. Quadrotor dynamics are considered complex and also have the nature of high nonlinearity, it has faced so many uncertainties during the mission as mentioned by Lee et al (2013). This is why the controller design of the quadrotor UAV is considered a hard task. It has many challenging sides. The control of the quadrotor is based on moving the flying robot from one position to another position in the three-dimensional space. This is called navigation of the quadrotor. Some uses make quadrotor control more challenging which has different tasks and aims which include navigation, optimal path tracking and obstacle avoidance.

Lee et al. (2012) presented the hovering control of the quadrotor. Using the Euler-Lagrange the quadrotor model is derived. The author presents two control structures; one for attitude control and the second one is for altitude control. The PID control is applied for attitude and the dynamic surface control method is applied for altitude control. The efficiency of the control system is proved through simulation. It was found that PID control is performed in control of pitch angle, however, roll angle has large steady-state errors were. Where PID controller for the adjustment of the position and orientation that quadrotor has. Because of the non-linear nature of the mathematical model and its complex nature, the application of the PID controller limits the performance. Matlab/Simulink simulation software is used for testing and simulation of the presented controller.

The paper (Li et al. 2011) presented the architecture and dynamic model which belongs to the quadrotor. PID controller is used in the paper for position regulation and quadrotor orientation. Because of the non-linear nature of the mathematical model and its complex nature, as we use the PID controller, it limits the performance of the quadrotor control. By using Matlab/Simulink simulation experiment is provided.

The previous researchers (Bouabdallah et al. 2004) and (Bouabdallah et al. 2007) used the LQR controller for quadrotor control and compared performances with the performances of the PID controller. Bouabdallah et al. (2004) demonstrated control techniques for a micro quadrotor. The approached control techniques are PID and LQ. PID is considered on simple dynamics, however, LQ is considered on the complete model. PID is used for the control of orientation angles. Test flights and simulations were performed in the lab.

Bouabdallah et al. (2007) demonstrated an algorithm of real-time control which is proposed for collision-free operations. It covers both path tracking and trajectory planning that is called quasi-optimal. Paper uses the full dynamic model the LQR is applied for quadrotor control and accurate path following was obtained. The control technique is standard linear and multi-variable.

Paper (Runcharoon and Srichatrapimuk 2013) proposed a controller called sliding mode that was used for the quadrotor have the desired position and yaw.

(Madani and Benallegue, 2006) used backstepping control, different, good and reasonable tracking was acquired for position and yaw angle. The algorithm presented in this paper is a nonlinear dynamic model. This controller is demonstrated to stabilize the whole system, dynamic relations of horizontal positions, vertical positon, yaw angle and up thrust force of the propeller. It is called an under-actuated system which is also called a quadrotor.

Fang and Cao, (2011) used an integrator backstepping algorithm for quadrotor control in order to remove the errors of steady-state, reduce two parameters as much as possible. These parameters are called response time and restrain overshoot. It is done by attitude and position tracking and control. This control method is aimed to achieve a quadrotor control that is robust. The method can approximately predict the disturbances online therefore the system can achieve better robustness.

Adaptive control algorithms have been applied in Diao et al. (2011) for improvement of the control performances of the control systems. The authors applied an adaptive controller which is continuous varies over time periods. They aimed to obtain good performance with instability in mass, the moment of inertia and aerodynamic damping coefficients. The control algorithm is Lyapunov-based. Errors of yaw and position tracking are tried to be set zero.

Palunko and Fierro, (2011) for quadrotors that have dynamic variations located in the center of gravity control. They used an adaptive control. The way they approach has feedback linearization. The aim is to propose and overcome trajectories and problems. It is done by changes in the dynamics in the COG(center of gravity). If there is a change occurs in the center of gravity there is reconfiguration takes place in the real life.

De Monte and Lohmann, (2013) used adaptive control with rectilinear distance (L1) for quadrotor control. There are error dynamics that occur because of the design of backstepping. The proposed L1 control is to deal with these dynamics which are also time-varying and nonlinear. This approach deals with the uncertainties and disturbances within the specified range. The model deals with model uncertainties of parameters and disturbances. As we progress practical application will occur and we will face external parameters such as wind and wind gusts. By using this approach, we will prevent these errors.

The paper (Falkenberg et al., presented a control method to avoid external disturbances and uncertainties. It presents a control method that performs quadrotor tracking irrespective of this two avoidance. It contains PD position control and attitude control with the description of quadrotor dynamics. The hovering test is shown.

The paper (Bai et al., 2012) designed a robust tracking algorithm for attitude control and to achieve asymptotic stability.

Another research (Tony and Mackunisy, 2012) designed a robust tracking algorithm and achieved asymptotic stability when parametric uncertainties and unknown nonlinear dynamics exist.

For heading and tracking, the research (Satici et al., 2013) has proposed robust and the L1-optimal algorithm for tracking attitude and heading therefore they achieved a reduction of error. (Falkenberg et al. 2012) and (Raffo et al. 2010) used H∝ controller for quadrotor control. The achievement in this proposed system is sustained disturbance rejection and useful robustness. (Lee et al., 2009) used a linearization model. It has feedback. By changing variables the nonlinear system model is transformed into a linear system. This system is equivalent.

For comparison between adaptive sliding mode control and feedback linearization, Lee et al., (2009) have research. The feedback controller with simplified dynamic was varying with noise that sensor has. This makes the system not robust. Adaptation rule is the main reason why the sliding mode deals with uncertainties and predicts them well and has sufficient performance. Santos et al., (2010) developed a fuzzy controller. This is used for the purpose of the control of the position of the quadrotor and is orientation. Dierks and Jagannathan (2010) developed an output feedback controller. Neural networks (NN) are used in the design. It is aimed at controlling the six degrees of freedom that four controlled parameters have. Boudjedir et al. (2012) proposed a controller that can work under sinusoidal disturbance. The authors used NN which is aimed to stabilize the quadrotor under this disturbance. Zeghlache et al., (2012) developed a combination of different control methods. It used a hybrid combination of the fuzzy controller with backstepping and sliding mode control and the chattering effect that the sliding mode control system has was eliminated. Zulu and John, (2014) presented the state of art approaches used for the control of quadrotors. Ajmera and Sankaranarayanan, (2016) presented a point-to-point control algorithm that moves the controller from one point to another point. Song et al., (2019) presented a control algorithm that works in the presence of dynamic and actuation faults variables. These are uncertain. This control is aimed to control the tracking of attitude and orientation of the quadrotor UAV has. A state-space mathematical model reflecting the nonlinearity comes with faults of actuation and external disturbances.

Neural networks (NNs) have function based on radial that has virtual parameters. The purpose of this NN is to predict algorithms. The adaptive control scheme is designed based on NN and also referred to as adaptive based fault-tolerant indirect adaptive fault-tolerant controller is proposed. It is based on NN. (Kose and Oktay, 2019) presented the modeling quadrotor UAV using PID controller in a noisy and noiseless environment. Zhang et al., (2018), presented an active disturbance rejection control (ADRC) scheme which is aimed to solve challenging and difficult tasks that the quadrotor unmanned aerial vehicle (UAV) control brings out. This system has nonlinearity which comes with a quadrotor dynamic nature. It has also strong coupling and sensitivity to outside effects and disturbance, Control of the quadrotor tracking brings out some problems. These are outside effects and some uncertainties that the model has. Wang and Hu, (2020) presented a solution for this rotation-based system. This controller is based on backstepping technology, with a performance controller. The proposed control system is estimation-free and does not depend on the exact knowledge of the model parameters. How effective is the system can be seen from the simulations. For the cases of varying time and the constraints on the output which are asymmetric Wang et al., (2020), presented the tracking of a quadrotor trajectory with 6 DOF(six degrees of freedom). The controller they proposed is used to find the upper bound of external interference online. The controller is an adaptive. On the other hand, Dynamic Surface Control (DSC) system is demonstrated for the problem of the ‘explosion of complexity’ that comes from the traditional backstepping design process where in the position control loop. Another controller is implemented for the attitude loop controller design. It is called Event-triggered. Finally, the simulation results are shown for proving and demonstrating how the designed control method has sufficient effectiveness. To reduce the wind effect and disturbance as much as possible Mohsen, et al.,(2019) designed a controller which is based on the backstepping method. It is called fractional-order sliding mode. It also aims the cancel the variations of the load and momentums of inertia which can have some effects on the quadrotor. The adaptive correcting coefficient predicts and evaluates the amount of load from the mass of the quadrotor. The robustness of the designed controller is proposed by using simulations under the presence of disturbances. N. Koksal et al., (2020) proposed a controller based on backstepping based. It is called indirect and direct adaptive. It controls the position, altitude, and attitude. To achieve control of the unmanned helicopter over the network Sharma and Kar, (2021) designed a backstepping controller. It also contains a state predictor. It contains delay of the state and input time. It is designed for controlling a quadrotor over a network under state and input time delay. Using measured delayed states the future states are predicted and the backstepping control law is applied based on these predicted future states Bhargavapuri et al., (2019) presented nonlinear backstepping controllers for control of a quadrotor where pitch varies. It is a robust controller. 6 degrees of freedom model is considered using rotor dynamics. Simulation is used for the evaluation of the performance of the control scheme. Ghadiri et al., (2021) has proposed a controller which is aimed to track of attitude and altitude of aircraft in finite time in bounded disturbances. Therefore they presented an adaptive non-singular terminal sliding mode control (ANTSMC). Tang et al., (2021) proposed a quadrotor controller to aim trajectory tracking control in a finite time and also tolerant to a fault. It is designed to get rid of outside effects and disturbances, uncertainties that are parametric and the controller also deals with actuator faults. In this process, we do not need a fault diagnosis mechanism. First, the terminal sliding mode control (TSMC) method is demonstrated to cancel and remove the uncertainties and faults that come from the actuators. Then, we need to get rid of the need for the previous information of the uncertainty bounds. Therefore, an adaptive fault-tolerant control (AFTC) is proposed for this purpose and they acquired trajectory with high precision in a known time. The Lyapunov theory proves how a closed-loop system has finite-time stability.

For a quadrotor under the effect of wind and such disturbances Zhao et al., (2019) proposed a double closed-loop controller. The proposed control scheme was adopted for active disturbance control which is aimed to remove disturbance and integral sliding mode control. The proposed method showed its efficiency in the experimental results. Alqaisi et al., (2020) presented Three Loop Uncertainties Compensator (TLUC) and Exponential Reaching Law Sliding Mode Controller (ERSM) for control of an Unmanned Aerial Vehicles (UAV) quadrotor. The TLUC can estimate uncertainties that vary with time, ERSIM provides control of some parameters. These parameters are position, attitude, and altitude. The performance is analyzed using the Lyapunov function. Lin et al., (2020) presented an even-triggered control strategy based on reinforcement learning to stabilize quadrotor UAV with actuator saturation. Two NN are used for the design of the controller. RL is applied for training. Qi et all., (2021) presented control of attitude of the quadrotor. This controller-based is on modified uncertainty and disturbance estimator (MUDE). It augmented to use a controller for quadrotors. By using the dynamic model of the actuator this controller is used. The stability of the control system is described. Lv et al.(2020) presented motion control of the quadrotor with a slung load control (QSL). The Lagrangian approach is used to represent a dynamic model of the QSL. A nonlinear three-loop cascade control scheme is designed for the velocity control achievement of QSL. Segun et al., (2020) presented a hierarchical control algorithm for controlling two rotors of quadrotors with a slung load. The paper modeled the two quadrotors dynamics with slung load system. To show how the controller is efficient the simulation results were shown.

Cai et al., (2020) presented a control system that uses PID controllers for trajectory control of quadrotor and disturbance reduction for the way surveillance. This controller is based on input disturbance which is equivalent. For control of tracking, there are four controllers. Half of the controllers are PI and the other half are PD. These controllers are used. Paper presented the System design, analysis of stability, and calculation of parameters. A robust PID control system is proposed by Miranda-Colorado and Aguilar, (2020) for the control scheme of the quadrotor UAV. The stability of the controller was studied by applying the Lyapunov technique. Numerical simulations and tests are given to demonstrate the performance of controllers. Kahouadji et al., (2020) presented modified super twisting control for control of the quadrotor attitude under the effect of uncertainty. Convergence and stability analysis is derived using the Lyapunov function. Kim et al., (2012) presented linear matrix equality (LMI) approach to the hovering control of nonlinear quadrotors. For evaluation of effectiveness then simulation results are provided. Local exponential stability is considered. Outeiro et al., (2018) presented a controller to achieve the control of the quadrotor. It uses height and yaw angle. This method have the ability to carry constant load previously added. The control methods which is proposed are steady-state Linear Quadratic Regulator-based (LQR). The system overall performance is obtained when the load was 10% of the vehicle mass. Noormohammadi-Asl et al., (2020) presented $H\propto$ control approach is used for the quadrotor control. Jin et al., (2020) considered position and its attitude trajectory for quadrotor surveillance using NN. For the Estimation of the outside effects and disturbances, NN is used to estimate the unknown uncertainties and to estimate disturbances NN is used. Pi et al., (2020) presented quadrotor control based on neural networks with model-free reinforcement learning. It uses an adaptive technique. This controller is called low-level. The algorithm tested for quadrotor hover and tracking tasks. Shao et al., (2020) presented the control of quadrotors for the purpose of the ground-based targets under parametric uncertainties, outside effects(disturbances) and noises servo tracking. Based on neural network and RISE control, a neuroadaptive integral control system is designed with asymptotic stability and robustness. Li et al., (2019) presented a robust controller consisting of radical basis function neural networks (RBFNNs) which are based on two parameters. One of them is proportional derivative-sliding mode control (RPD-SMC) and the other one is the robust integral of the signum of error (RISE) control. RPD-SMC is used to compensate disturbances, RISE is used to handle parametric uncertainties. The paper (Nekoukar and Dehkordi, 2021) had designed a controller for quadrotor stabilization which is an adaptive fuzzy terminal sliding mode with PD(proportional derivative) for a robust flight system. It is also used for tracking a previously defined flight path under the existence of outside effects and disturbances and some uncertainties that the model has. The designed PD controllers obtain the desired quadrotor attitude. It has also a terminal sliding mode which has the ability to control the rotation speed of rotors by adjusting it. By using Mamdani fuzzy systems which are adaptive, the dynamics and the mentioned disturbances are obtained and determined. The result of the simulation was given to prove how the control system has efficiency.

Another fuzzy controller is shown in the paper (Mahmoodabadi and Babak, 2020). This robust controller is based on a Linear Quadratic Regulator. The optimization of controller parameters which are membership functions was done by multi-objective high exploration particle swarm optimization. The simulation has been done using 4 DOF quadrotors.

CHAPTER III

Methodology

Structure of Quadrotor

The Quadrotor has four rotor-driven rotors, as shown in Figure 3.1, placed in orthogonal directions. Motors with rotation propellers generate power, these are F1, F2, F3 and F4. The rotors 1 and 3 turns opposite the clock, but the left and right rotors- 2 and 4 rotate clockwise (see Figure 3.2). When we control the θ, roll ϕ and yaw ψ angles of the quadrotor, it tracks the desired location. By selecting rotating rotor speed we can select the required pitch, roll and yaw angles values. In airplane mode, the quadrotor can generate its lifting power by controlling the pitch angle rotor speed. Motors rotate at the same angular speed. When selecting the propeller speed forward and rear pitch angle, as we select the propeller speed left and right the folding angle is controlled. The speed difference of the two forward left and reverse propeller pairs allows for the choice of positive or negative yaw angles.

Figure 3.1. Quadrotor.

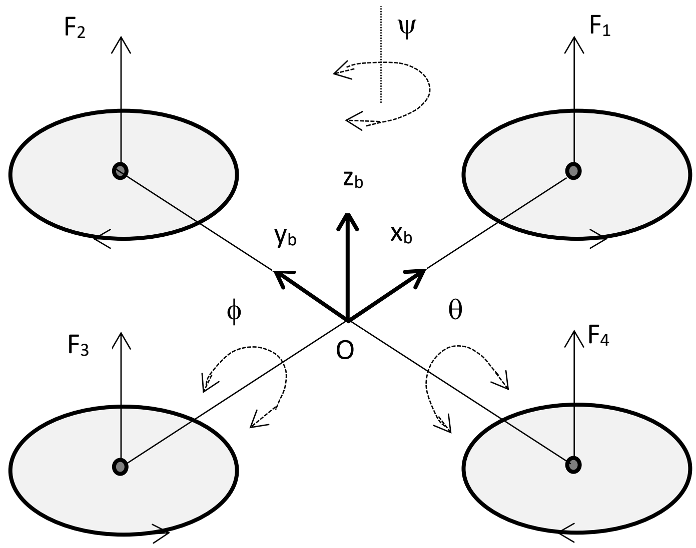


Figure 3.2. Configuration of Quadrotor

The motor speeds of the quadrotor are the main problem. The quadrotor parameters which are speed and position are the main parameters to maintain the speed and position of the quadrotor. Therefore, we achieve control.

Quadrotor Kinematics

We demonstrate the Kinematics of the quadrotor with two different angle frames. They are called the body-centered frame which is denoted by B={xb,yb,zb} and the earth-centered frame which is illustrated by E={x,y,z}. These are coordinates of the quadrotor in two different coordinate systems. One of them is the local and the other one is the global coordinate systems. The center of mass of the quadrotor is the O point which is the origin of the body coordinate system. There are relations of the earth-centered with body-fixed frames. These matrices below are called the Rotation matrix. The matrix equation of transforming the earth-centered frame to body-centered frame is presented at 3.1 below

$$R = \begin{vmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\ \cos\psi\sin\theta\, sin\,\phi - \cos\phi\sin\psi & \cos\phi\cos\psi + \sin\phi\sin\psi\sin\theta & cos\,\theta sin\,\phi \\ \cos\phi\cos\psi\, sin\,\theta + \sin\phi\sin\psi & \cos\phi\sin\psi\, sin\,\theta - \cos\psi\sin\phi & cos\,\phi cos\,\theta \end{vmatrix} \quad (3.1)$$

The equation of matrix of transforming body frame to earth frame is presented as

$$R = \begin{vmatrix} \cos\psi\cos\theta & \cos\psi\sin\theta\, sin\,\phi - \cos\phi\sin\psi & \cos\phi\cos\psi\, sin\,\theta + \sin\phi\sin\psi \\ \cos\theta\, sin\,\phi & \cos\phi\cos\psi + \sin\phi\sin\psi\sin\theta & \cos\phi\sin\psi\, sin\,\theta - \cos\psi\sin\phi \\ -sin\,\theta & \cos\theta\sin\phi & cos\,\phi cos\,\theta \end{vmatrix} \quad (3.2)$$

In the thesis, we use x,y,z coordinates. These coordinates are called Euler.

Modeling body

Figures of solid body movement under the outer wrench F are used in the center of the weight and specified in relation to the body link frame. This section introduces the model used in the built-in controller. During this time, To achieve active and effective independent quadrotor flight, the helicopter has had advanced control parameters for active independent aircraft. Body strength with the external force which is demonstrated in a fixed body structure with Newton-Euler formalism in the equation below exerted to the center of the weight.

$$\begin{bmatrix} mI_{3\times3} & 0 \\ 0 & I \end{bmatrix} \begin{bmatrix} \dot{V} \\ \dot{\omega} \end{bmatrix} + \begin{bmatrix} \omega \times mV \\ \omega \times I\omega \end{bmatrix} = \begin{bmatrix} F \\ \tau \end{bmatrix} \quad (3.3)$$

This equation is called the Newton-Euler equation in physical links. Provides a global definition of the dynamics of the solid body under the outer screw. Note that line and angular movements are combined as the line speed in body curves depends on the current movement. It is also possible to write Newton-Euler statistics related to the local integration framework. This version is explored in Exercises 4 and 5. Here, too, linear and angular motion figures are combined, so that the translation movement is still dependent on rotational motion.

Let us consider the fixed E frame of the earth and the B-shaped frame as shown in Figure 3. Euler Angles are used. As we use these angles, the axis position in the dimension is given by rotating R from B to E. The R ∈ SO3 is a rotation matrix. The axis system (Figure 3.3) corresponds to the N, E, D (North, East, Low) levels, which depends on the inertial sensor coupling mechanism. By combining theoretical and blade element theory aerodynamic forces and times are taken(Badullah, 2007; Nekoukar and Dehkordi, 2021).

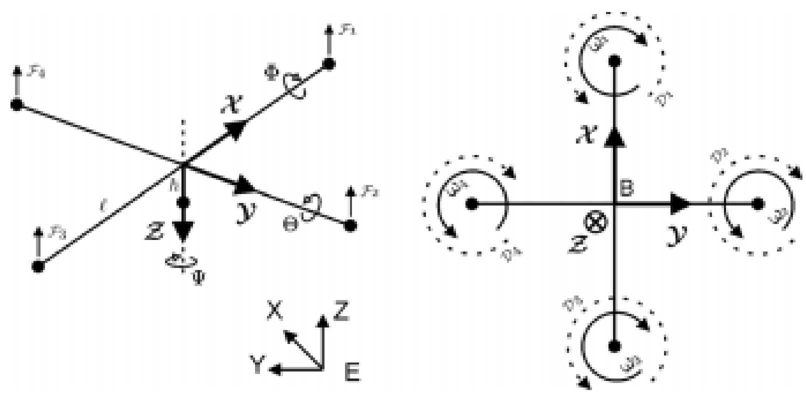


Figure 3.3. The frame system

σ: solidity ratio	λ : inflow ratio
a : lift slope	υ : induced velocity
μ : rotor advance ratio	ρ : air density

The Force of thrust is the result of the direct forces that acts on all aspects of the propeller. The horizontal forces applied to all the elements of the blade is called Hub Force.

Rotation Matrix

Solid rotation of space can be done in parameters as we use different methods. An examples can be given to methods such as Quaternions, Euler angles and Tait-Bryan angles. Tait Bryan angles ("Cardano angles") are widely applied in the area of aerospace engineering. These are referred to as "Euler angles". It brings discussion that contradicts the literal use of "Euler angles". This is a mathematical demonstration of the all three axes around potential axes (many principles) that are often confused in books, articles, and papers. In the field of aerospace engineering, the three axes are shown as handcrafts that move in the vertical direction of the x, the right side of the direction y(positive side), and the lower vertical side parallel to the point z which is positive.

These individual angles are the roll, pitch and yaw. When we consider the right-centered integration system, the three cycles are defined separately as:

• R(x, φ), x-axis.

• R(y, θ), y-axis.

• R(z, ψ), z-axis.

Dynamic Model of Quadrotor

The flexible Quadrotor model is derived by using equations that are called Newton-Euler (Badullah, 2007) method. For this purpose, we consider that the body of the quadrotor is solid, pushing and pulling are accompanied by a square of speed. The thrust or torque produced by the force of each propeller becomes directly proportional to its tilt or pull. Each rotor in the quadrotor has a separate stand. That is the result of a thrust in the quadrotor that may be generated as:

$$F_i = b\Omega_i^2 \tag{3.4}$$

Where b is a constant trust is determined by a static trust test. If we assume that the turbulence of each propeller is equal to its reliability the maximum reliability will be $= \sum_{i=1}^{4} F_i$. The resulting torque applied to the quadrotor can be generated as

$$\tau_i = (-1)^i c_\tau F_i \tag{3.5}$$

Here c_τ always remains. Then the cumulative thrust T and the full-time vector τ which is in the body structure is shown as

$$\begin{bmatrix} T \\ \tau_\phi \\ \tau_\theta \\ \tau_\psi \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & l & 0 & -l \\ l & 0 & -l & 0 \\ -c_\tau & c_\tau & -c_\tau & c_\tau \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{bmatrix} \tag{3.6}$$

With a solid quadrotor body, using the Newton-Euler method dynamic equation will be formulated as

$$ma = F_p + F_g + F_a + F_r \tag{3.7}$$

$$J\grave{}\Omega = T_g + T_p + T_a + T_r - \Omega \times J\Omega \tag{3.8}$$

Above m introduces the quadrotor mass, where an (acceleration) is shown. It is the in the inertial frame and centered, J the inertial matrix time, aerodynamic and residual force formulas, F_a= [F_{ax}, F_{ay}, F_{az}]^T and F_r = [F_{rx}, F_{ry}, F_{rz}]^T variables are unknown. Fg and Tg gravity and torque. Fp and Tp generating power and torque per quadcopter motions, respectively. By using aerodynamic, and residual torques T_a = [$T_{a\phi}$, $T_{a\theta}$, $T_{a\psi}$]^T and T_r= [$T_{r\phi}$, $T_{r\theta}$, $T_{r\psi}$]^T. Quadrotor has angular velocity. It is referred Ω = [p, q, r] T and it is at body frame will be calculated by

$$\Omega = \begin{bmatrix} 1 & \sin\phi\tan\theta & \cos\phi\tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi\sec\theta & \cos\phi\sec\theta \end{bmatrix}^{-1} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} \tag{3.9}$$

The J(inertia matrix) is described by

$$\boldsymbol{J} = \begin{bmatrix} I_x & I_{xy} & I_{xz} \\ I_{xy} & I_y & I_{yz} \\ I_{xz} & I_{yz} & I_z \end{bmatrix} \tag{3.10}$$

and

$$F_g = [0 \quad 0 \quad -mg]^T \tag{3.11}$$

$$F_p = \begin{bmatrix} \cos\phi\cos\psi\sin\theta + \sin\phi\sin\psi \\ \cos\phi\sin\psi\sin\theta - \sin\phi\cos\psi \\ \cos\phi\cos\theta \end{bmatrix} \tag{3.12}$$

$$T_g = [-qI_r\Omega_r \quad pI_r\Omega_r \quad 0]^T \tag{3.13}$$

$$T_p = [T_\phi \quad T_\theta \quad T_\psi]^T \tag{3.14}$$

that g is called gravitational force. It is a constant parameter. The inertial moment is called Ir is the inertial moment parameter of the rotors and $\Omega_r = \sum_{i=1}^{4} \omega_i$ and we can get the equation of the quadrotor linear motion as shown below

$$\begin{aligned} \ddot{x} &= \frac{1}{m}[(\cos\phi\cos\psi\sin\theta + \sin\phi\sin\psi)T + F_{ax} + F_{rx}] \\ \ddot{y} &= \frac{1}{m}\left[(\cos\phi\sin\psi\sin\theta - \sin\phi\cos\psi)T + F_{ay} + F_{ry}\right] \\ \ddot{z} &= \frac{1}{m}[(\cos\phi\cos\theta)T - mg + F_{az} + F_{rz}] \end{aligned} \quad (3.15)$$

We can calculate the equation of angular movements but it would be very complex. For simplicity, the angular motion is shown as

$$\begin{bmatrix} \ddot{\phi} \\ \ddot{\theta} \\ \ddot{\phi} \end{bmatrix} = f_r(\phi, \theta, \psi, \dot{\phi}, \dot{\theta}, \dot{\psi}) + g_r(\phi, \theta, \psi, \dot{\phi}, \dot{\theta}, \dot{\psi})\left[T_g + T_p + T_a + T_r\right] \quad (3.20)$$

Where f_r and g_r are the matrix of Euler angles and their first derivatives.

The variables F_a, F_r, T_a and T_r are unknown. Measurements in our experiments in moderate conditions where these variables are taken as zero.

The symbols f_r and g_r are the matrix of Euler angles and their first derivative.

The variables F_a, F_r, T_a and T_r are not known. Ratings in our experiment in moderate environments where these variables are considered zero

The dynamic equation quadrotor will be built using the following calculations (Badullah, 2007; Nekoukar and Dehkordi, 2021).

$$\ddot{x} = (\cos\psi \sin\theta \cos\phi + \sin\phi \sin\psi)\frac{U1}{m} \quad (3.21)$$

$$\ddot{y} = (\sin\psi \sin\theta \cos\phi - \sin\phi \cos\psi)\frac{U1}{m} \quad (3.22)$$

$$\ddot{z} = -g + (\cos\theta \cos\phi)\frac{U1}{m} \quad (3.23)$$

$$\ddot{\phi} = \frac{(I_y - I_z)}{I_x}\dot{\theta}\dot{\psi} + \frac{J_r}{I_x}\dot{\theta}\Omega + \frac{l}{I_x}U_2 \quad (3.24)$$

$$\ddot{\theta} = \frac{(I_z - I_x)}{I_y}\dot{\phi}\dot{\psi} - \frac{J_r}{I_y}\dot{\phi}\Omega + \frac{l}{I_y}U_3 \quad (3.25)$$

$$\ddot{\psi} = \frac{(I_x - I_y)}{I_z}\dot{\theta}\dot{\phi} + \frac{l}{I_z}U_4 \quad (3.26)$$

The angles θ, ϕ, ψ are called the pitch, roll and yaw; We have also the moment of inertia referred to as Ix, Iy, Iz in axes, y and z respectively; Rotor has inertia and it is called Jr; Ω angular rotor speed, arm length of the rotor is called l which is from the original base of the frame; The input signals to the four motors are referred as U1, U2, U3 and U4 parameters. They are illustrated as;

$$U_1 = b(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2) \tag{3.27}$$

$$U_2 = b(-\Omega_2^2 + \Omega_4^2) \tag{3.28}$$

$$U_3 = b(\Omega_1^2 - \Omega_3^2) \tag{3.29}$$

$$U_4 = d(-\Omega_1^2 + \Omega_2^2 - \Omega_3^2 + \Omega_4^2) \tag{3.30}$$

CHAPTER IV

Design of Control System for Quadrotor

PID Control

We can say the Pid is the most widely used control method in the industry. The conventional PID has some advantages and one of them is that the easy adjustment parameters of the parameter, easy to design, also have useful durability. However, with quadrotors, we face some major challenges, including the linear inconsistencies because of the mathematical model and the model has negative nature. This is because the unbalanced or modeling mathematical incorrectly at other dynamics. Therefore using a PID controller on a quadrotor reduces its efficiency. The PID design is used to achieve the position by controlling parameters, while the DSC(dynamic surface control) is used to control the height.

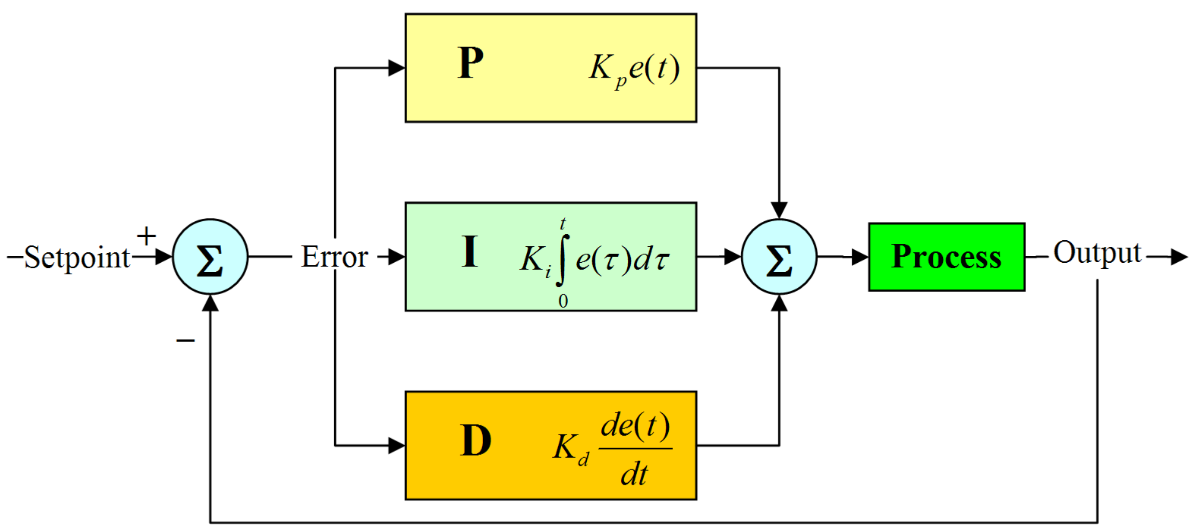


Figure 4.1. PID control scheme

Applying the stability conditions of Lyapunov (Lee et al). they can show that all quadrotor signals were tied in the same way at the end. Therefore the quadrotor has enough stability to adapt. Through the simulations and experiments, however, it is shown the PID controller to do better at tracking the pitch angle, while larger stability instances can be detected in tracking the roll angle. PID control system was used to control for quadrotor position and its place. The benefits of the PID parameter are carefully selected. The PID performance has shown good stability. It has a satisfactory response time. It has also a steady-state error and a slight overshoot in the graph.

$$u(t) = K_{zh}e(t) + K_{zh}\int_0^t e(v)d(v) + K_{dz}\frac{de(t)}{d(t)} \tag{4.1}$$

$$u(t) = K_{p\phi}e(t) + K_{i\phi}\int_0^t e(v)d(v) + K_{d\phi}\frac{de(t)}{d(t)} \tag{4.2}$$

$$u(t) = K_{p\theta}e(t) + K_{i\theta}\int_0^t e(v)d(v) + K_{d\theta}\frac{de(t)}{d(t)} \tag{4.3}$$

$$u(t) = K_{p\psi}e(t) + K_{i\psi}\int_0^t e(v)d(v) + K_{d\psi}\frac{de(t)}{d(t)} \tag{4.4}$$

The equations shown above has shows the PID equations for controlled parameters. For each controlled parameter, we have K coefficient constants. By varying these K parameters we achieve optimal K values for each parameter. This leads to control of the quadrotor.

The presented PD controller for each orientation angle is shown as:

$$U_{2,3,4} = k_{\phi,\theta,\psi}(\phi,\theta,\psi) + d_{\phi,\theta,\psi}(\phi,\theta,\psi) \tag{4.5}$$

Every dynamic model is built on the basics of physics and aerodynamics, which allows for the easy acquirement of the visual parameters. The aim of the designed rotor dynamics is to get the flexibility of the motor, electrical power, and propeller. This should be done at the same time. The result is a set of statistics that describe the flexibility of a car not only in rotation but also in movement.

Fuzzy Control

Intelligent control algorithms use AI methods, to achieve control of the system. These methods are such as artificial intelligence, neural networks, genetic algorithm and machine learning. The mathematics they have consisted of great uncertainty and is considered complex. This causes the required computational area to have limited the application of these controllers. The Control area is not only made up of fuzzy logic and Neural networks. These two are mostly used. There are many algorithms that exist. They are still being developed. Ignorant logical algorithms deal with logic with multiple values, not different levels of truth. During simulation and tests, a fuzzy-based controller was used to maintain the attitude and altitude for the quadrotor control. It has also feedback. However, the testing part is the main limitation of this work and also there are errors with the input variables.

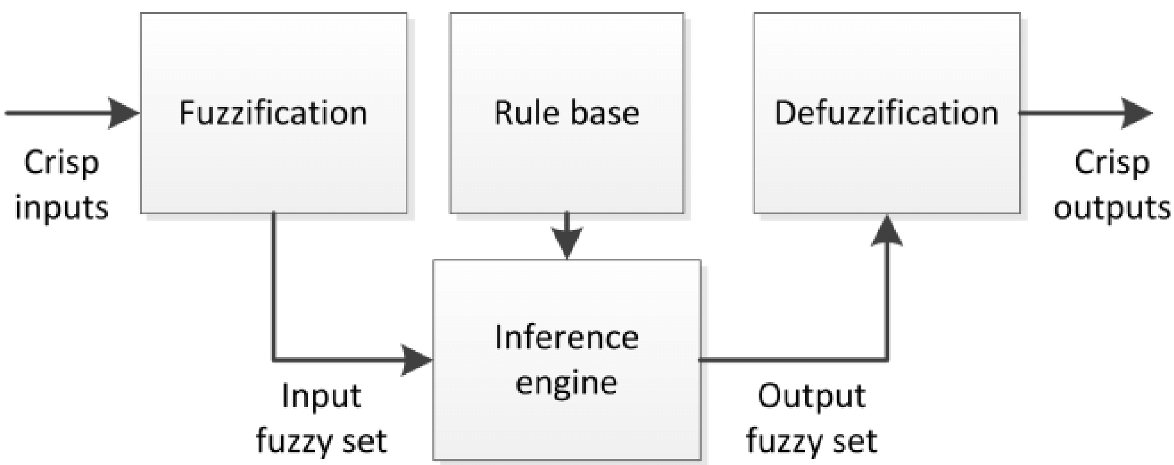


Figure 4.2. Structure of Fuzzy System

There is a special type of information-based control which is called Fuzzy control. When we consider building a fuzzy control system, the need for an accurate mathematical model is not required. We need only relevant information and rules of the working conditions of the plant. These are used for designing a set of control rules. These languages use a simple relationship for combining the particular region of a plant with the control action. We obtain accurate numerical. Then we convert them to the membership variables in the language.

For FL controls the input is the error and rate of the error change is illustrated as:

$$e(t)=G(t)-y(t); \quad de(t)/dt; \tag{4.6}$$

where G(t) is the desired signal, y(t) is plant output.

To determine the output signal of the controller, heuristic rules based on expert knowledge are used. As a testing, Fuzzy Logic applies rule: If e(t) is NB and ce(change in error) is NB then the action (KI) to take place is PB. The e(t) is NB and ce is NB defines another variable. There are many ways of deriving the membership value for the variable. One of the fuzzy rules has been chosen. The method used to build and construct fuzzy rules is trial and error.

For defuzzification, we use the center of the mean. It is selected because of its simplicity. It is shown as:

$$K_I = \sum_{j=1}^{n} \mu_j u / \sum_{j=1}^{n} \mu_j \tag{4.7}$$

In the equation above, μ_j is defined as the membership value of a linguistic variant that recommends a fuzzy control action. The u is the center value corresponds to the fuzzy terminology that we use in the fuzzy controller. The evaluation of the designed fuzzy scheduling control scheme is defined by using some parameters. These are called Membership functions and the knowledge based rules.

Fuzzy Scheduling Control Design for Quadrotor

In essence, we have two parameters to control the quadrotor; attitude and altitude. For this purpose, we propose a fuzzy scheduling control. Given that the PID controller is used in the industry where operations have linear nature. The values of the PID control k constants are selected based on the plant models or the plant coefficient. When a plant is characterized by indirect rotation, the uncertainty of external disturbances and outside effects. An example can be given such as wind. Then the use of a PID controller for the quadrotor becomes very difficult. When plants appear indirectly when the controls used do not adequately describe the imaginary problems. In the largest rest period of operation, effective crop management is very important. In order to effectively control such flexible plants, determining the corresponding values of the control coefficients is very important. We need to acquire an accurate time response of the control system. One of the methods for these circumstances is to exploit the PID coefficients.

Drone movements in x, y and z are controlled by 3 controllers; each controls the height, folding and precision level. PID controls are used as the main controller. While fuzzy is used as a fuzzy scheduler of the PID K parameter corresponding to the operating environment of the drones, tested in the error area. All fuzzy scheduling PID has an identical scheme. Figure 4.3 shows Fuzzy's advantage of setting the PID for x-area. In the case of y and z, the z has the same order. This block contains PID signals and a Fuzzy scheduler. In PID controls, the general equation for the used controller is indicated as

$$u(t) = K_P e(t) + K_I \int e(t)dt + K_D \frac{de(t)}{dt} \tag{4.8}$$

The proposed fuzzy scheduling control system tests and uses a fuzzy ruler to generate the coefficients of the PID control. In this figure, depending on the error values and the error change the coefficients of the controller are determined. Error-correlation and error-correction with Fuzzy control coefficients are provided in the tables. Table 1 presents the correlation between error and change-error and proportional coefficient Kp, Table 2 presents the correlation between error and change-error and the different coefficient Kd, Table 3 presents the correlation between error and change-error and the critical coefficient Ki. These organizations are represented using the If-Then rules. The error values of the error and the variance of the error of the output and the equal coefficients, differences and combinations are represented by linguistic words. The triangular membership functions represent the variables in Figure 4.3 (a,b) and in Figure 4.4(a,b,c) which are linguistic terms of the input and output.

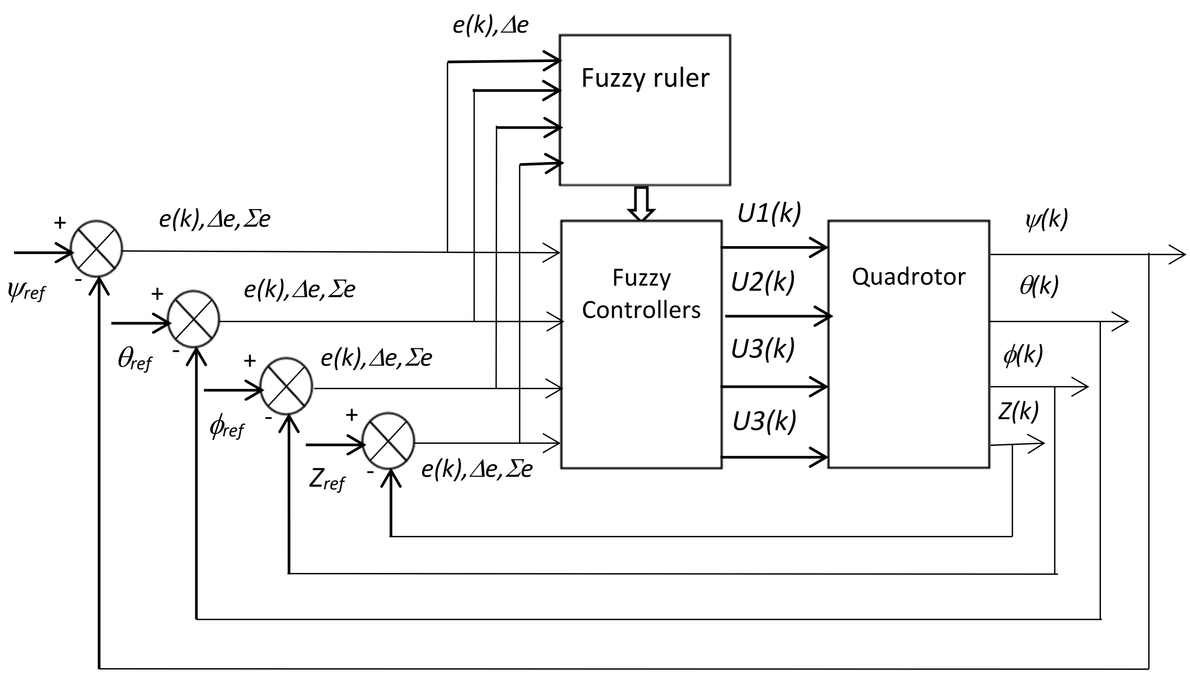


Figure 4.3: Fuzzy scheduling controller structure.

Table 1. Fuzzy rules for the proportional coefficients

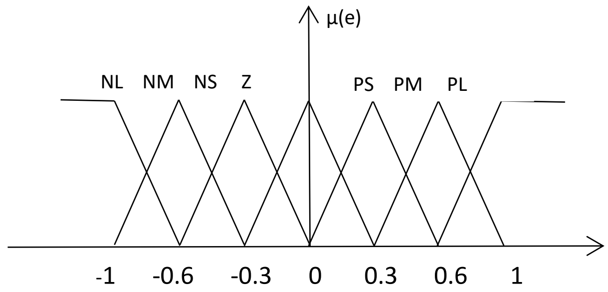
Kp’		Change in Error ($\dot{e}$)						
		NL	NM	NS	Z	PS	PM	PL
Error (e)	NL	L	L	L	L	L	L	L
	NM	S	M	L	L	L	M	S
	NS	S	S	M	L	M	S	S
	Z	S	S	S	M	S	S	S
	PS	S	S	M	L	M	S	S
	PM	S	M	L	L	L	M	S
	PB	L	L	L	L	L	L	L

Table 2. Fuzzy rules for the differential coefficients

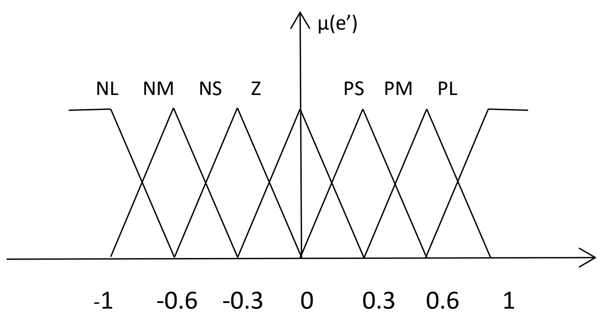
Kd’		Change in Error ($\dot{e}$)						
		NL	NM	NS	Z	PS	PM	PL
Error (e)	NL	S	S	S	S	S	S	S
	NM	L	M	S	S	S	M	L
	NS	L	L	M	S	M	L	L
	Z	L	L	L	M	L	L	L
	PS	L	L	M	S	M	L	L
	PM	L	M	S	S	S	M	L
	PB	S	S	S	S	S	S	S

Table 3. Fuzzy rules for the integral coefficients

Ki’		Change in Error ($\dot{e}$)						
		NL	NM	NS	Z	PS	PM	PL
Error (e)	NL	L	L	L	L	L	L	L
	NM	S	M	L	L	L	M	S
	NS	S	S	M	L	M	S	S
	Z	S	S	S	M	S	S	S
	PS	S	S	M	L	M	S	S
	PM	S	M	L	L	L	M	S
	PB	L	L	L	L	L	L	L



(a)



(b)

Figure 4.4. Membership functions defined for (a) error, (b) change-in-error

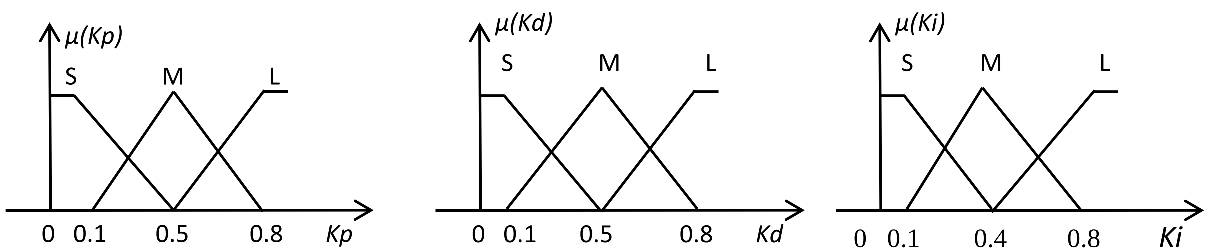


Figure 4.5. Membership functions defined for (c) Kp, (d) Kd and (e) Ki

The fragment of the If-Then fuzzy rule base is represented as

If error=NL and change-in-error=NS Then Kp=L and Kd=S and Ki=L
If error=NM and change-in-error=NM Then Kp=M and Kd=M and Ki=M
If error=NS and change-in-error=PM Then Kp=S and Kd=L and Ki=S
If error=Z and change-in-error=PM Then Kp=S and Kd=L and Ki=S
If error=PS and change-in-error=Z Then Kp=L and Kd=S and Ki=L

Figure 4.6. Fragment of the fuzzy rule base

where NL is called negative large, NM- called negative medium, NS – called negative small, Z- called zero, PL is called positive large, PM- called positive medium, NS – called positive small, L- called large, M- called medium, S- called small.

We need to find the K(Kp, Kd and Ki) coefficients. In the thesis, we use max-min composition for this purpose. Max-min is applied to find Kp, Kd and Ki coefficients. The proposed fuzzy controllers are applied to control the four parameters and angles; altitude Z, θ pitch, roll angle(ϕ) and yaw (ψ). For the flight mode, k parameters of controlled variables are determined. At the end, Kp, Kd and Ki parameters that we defined, are scaled. It is done by having maximum and minimum values of the K coefficients of the plant.

$$Kp' = Kpmin + (Kpmax - Kpmin) * Kp \quad (4.9)$$

$$Kd' = Kdmin + (Kdmax - Kdmin) * Kd; \quad (4.10)$$

$$Ki' = Kimin + (Kimax - Kimin) * Ki; \quad (4.11)$$

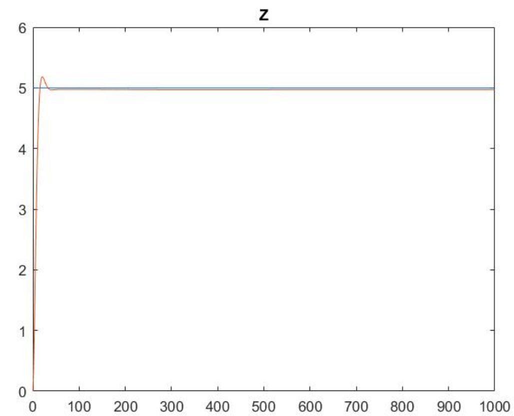
CHAPTER V

Simulations

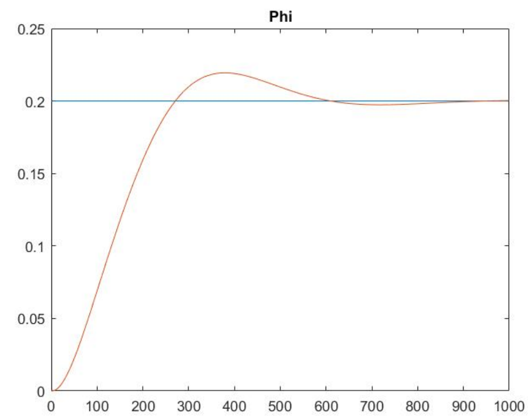
We used our research lab and Matlab software for the quadrotor controller design. At first, before starting the implementation, we tested the proposed fuzzy scheduling controllers. We used dynamic equations of the quadrotor for the control. The controlling attitude parameters which are roll, yaw and pitch and altitude parameter which is upthrust of the quadrotor has been applied in this research. We used the following parameters for the simulation of the fuzzy scheduling controller:

Half-length l=0.17 m,
Thrust coefficient b=3.13*10^(-5),
Drag coefficient d=1.1*10^(-6),
Mass m=0.38 kg,
Moment of inertia of rotor Jtp = 0.00006 kg.m2,
Moment of inertia on x axis Ix=0.0086 kg.m2,
Moment of inertia on y axis Iy=0.0086 kg.m2,
Moment of inertia on z axis Iz=0.0172 kg.m2.

Simulations have been done for controlling the four parameters of the quadrotor. Those are pitch, yaw, upthrust and roll In the first stage we did simulations using a PID control system. The PID control system was designed using the structure given in Figure 4.1. After the design, the altitude and attitude control of the quadrotor was implemented. Figure 5.1 demonstrates the plotted graph of the time response characteristic of altitude and attitude applied by the PID control system. Altitude and attitude variables are trust, roll, pitch, and jaw control variables of the quadrotor. In the second stage, we have implemented fuzzy control of trust, roll, pitch, and jaw angles quadrotor. Figure 5.2 demonstrates the fuzzy control system applied, the plotted the time response characteristic graph of altitude and attitude. As shown very smooth control of variables was obtained.



(a)



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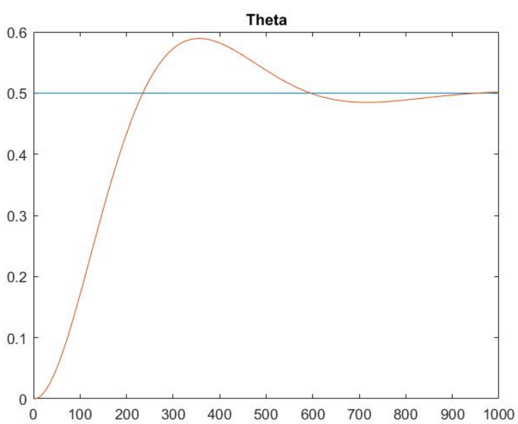
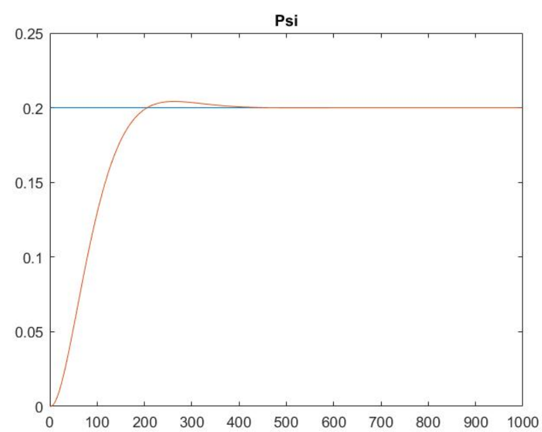


(c)



(d)

Figure 5.1. PID Response characteristic for (a) altitude(Z), (b) roll angle (ϕ), (c) pitch angle(θ) and yaw angle (ψ).

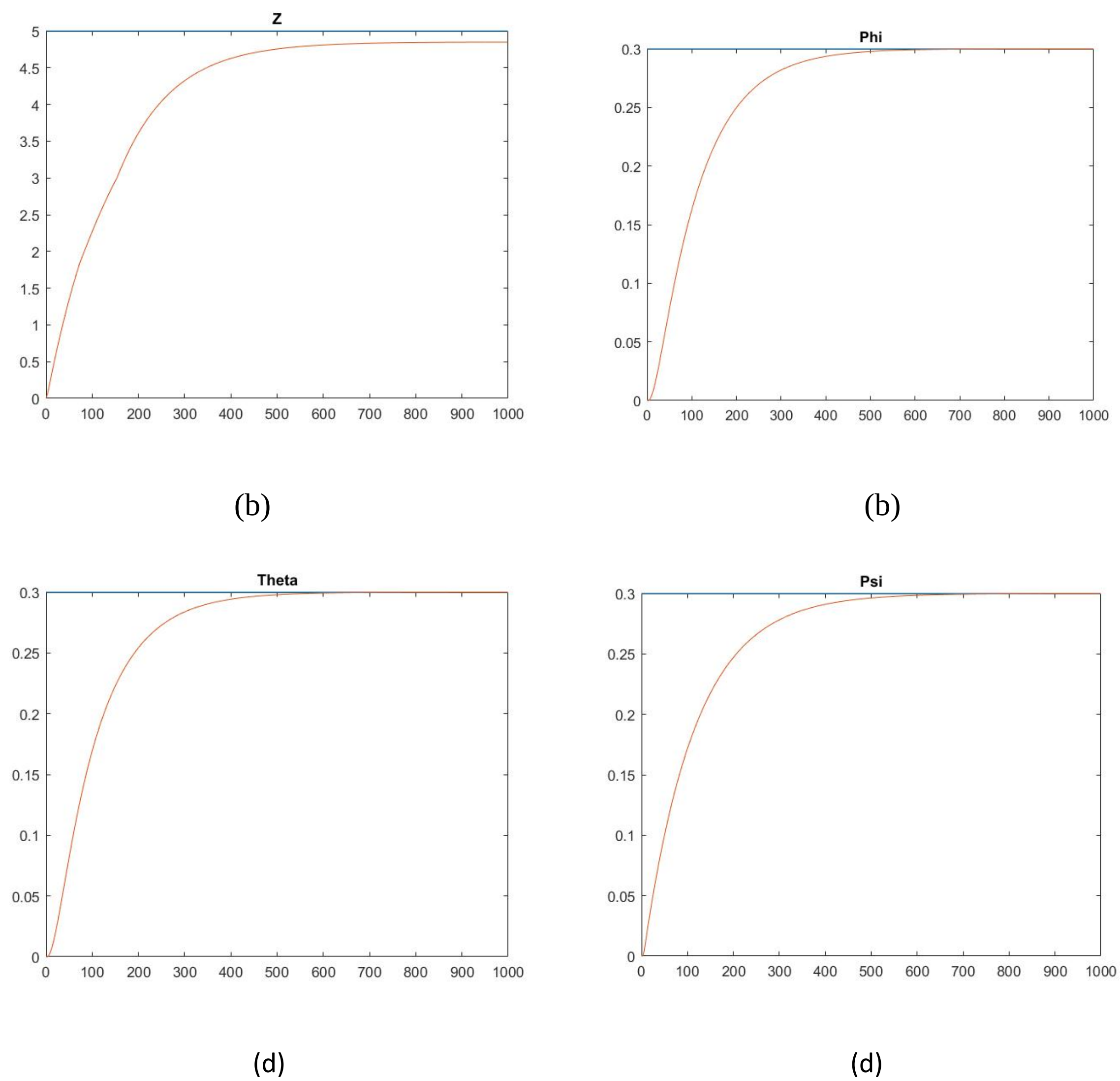


Figure 5.2. Fuzzy Response characteristic for (a) altitude Z, (b) roll angle ϕ, (c) pitch angle θ and yaw angle ψ.

In the next stage, we used some reference signals to achieve different values for the simulation. These signals are G, where G=(Z, yaw, pitch, roll). We take (0, 0, 0, 0) points for starting, but then we have made variations in reference signals for thrust, yaw, pitch, roll in each 500 steps as

(3;0.3;0.3;0.3)

(5;0.5;0.5;0.5),

(3;0.3;0.3;0.3),

(5;0.5;0.5;0.5).

If it appears we are using different reference signals in the control system. Theoretically, voice angles and rolls should be negligibly small. However, in the real world, the value these two angles have do not matter. By controlling these angles the quadrotor area is controlled. Their values are important in maintaining control of the position. For performance results, root means square error (RMSE) of the four controlled parameters(yaw, pitch, roll, and altitude) are used. By using PID time response characteristics we obtained the plot that shows the time response characteristic of these parameters. We obtained characteristics of time response of altitude. By using the proposed fuzzy scheduling control system we obtained two plotted graphs. One is time response and the other is error plot. Figure 5.3 demonstrates the plotted graph for the altitude characteristic which is obtained by applying the fuzzy scheduling controller. Figure 6.4 shows the plotted graph of the errors of these parameters. This plot is also obtained by using the fuzzy scheduling control system.

For performance evaluation of the proposed system, we determine the RMSE values of response characteristics. By using transient response characteristics we obtain RMSE values of the control system obtained from the controllers that we tested. The RMSE values are shown in table 1. The purpose of this table is to show the comparison of obtained results between the fuzzy scheduling controller and PID control system. Comparative results demonstrate how proposed the control system is efficient and has an advantage over other controllers.

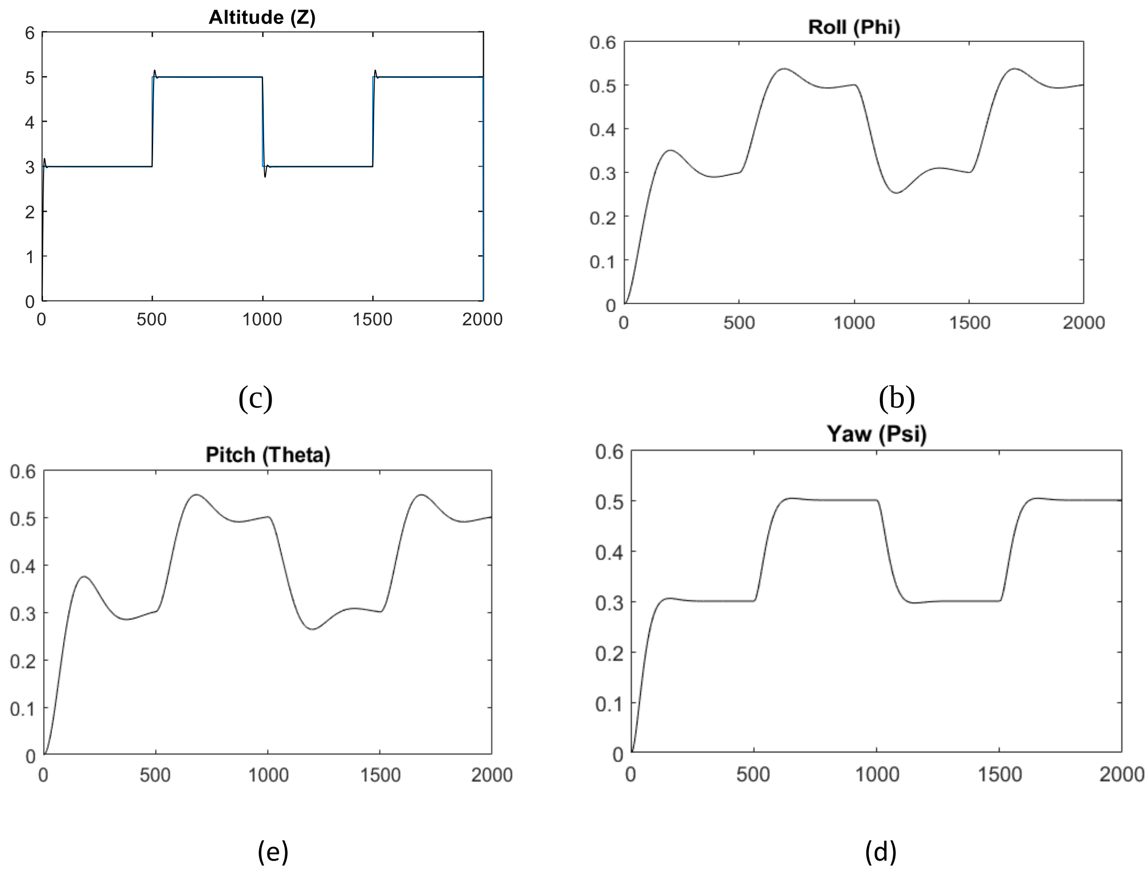
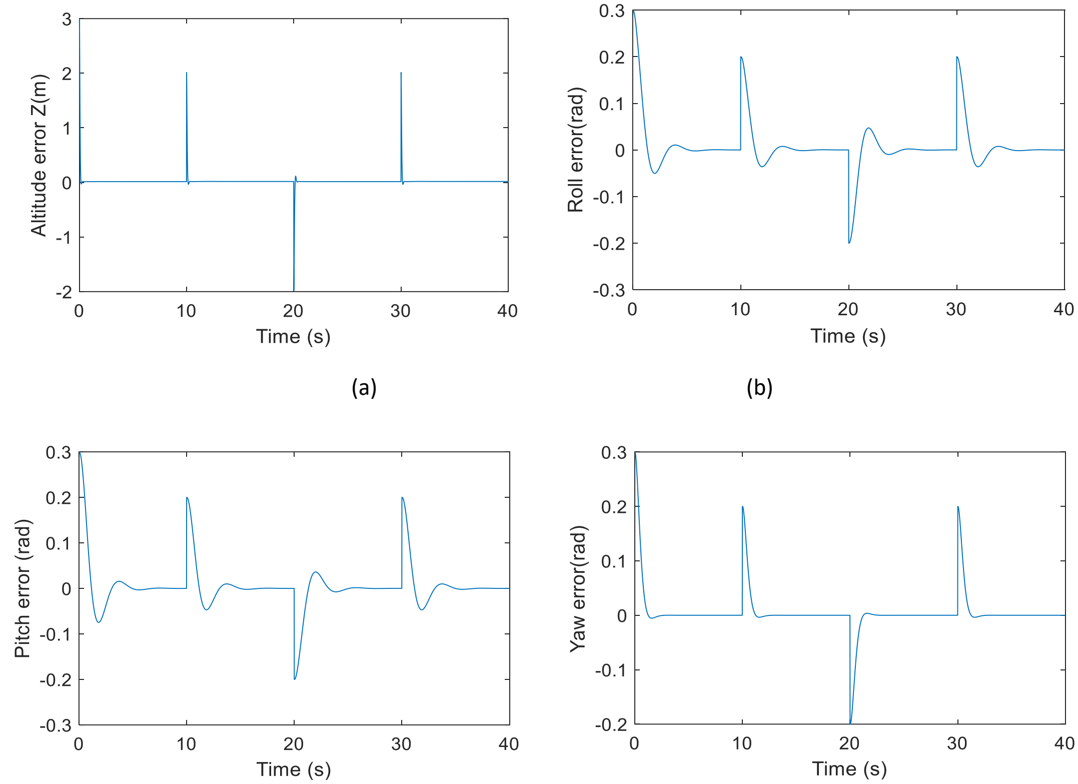


Figure 5.3. Fuzzy Scheduling Response characteristic for (a) altitude Z, (b) roll angle ϕ, (c) pitch angle θ and yaw angle ψ.



(c) (d)

Figure 5.4. Plot of error for (a) altitude (Z), (b) roll angle (ϕ), (c) pitch angle (θ) and (d) yaw angle (ψ).

Table 4. Obtained Performance characteristics

Type of controller RMSE values	Altitude (Z)		roll angle ϕ,		pitch angle θ		yow angle ψ	
	SSE	RMSE	SSE	RMSE	SSE	RMSE	SSE	RMSE
PID controller	64.384	0.1795	13.2685	0.0815	14.08	0.08393	8.294	0.0644
Fuzzy	2007.7	1.4176	6.13126	0.0783	5.890	0.07678	5.429	0.0737
Fuzzy Scheduling controller	53.189	0.163	11.847	0.0769	11.69	0.0764	7.42	0.0609

The proposed controllers have been applied for the control of the UAV aircraft designed and manufactured in our Robotics lab. During tests, we designed the Printed circuit board (PCB). It is mounted and used in UAV aircraft. It contains the pins for components such as Imu, XBee, GPS(for future research and development), Teensy 3.2, microprocessor, 5V and 3C input source, bldc, and servo motor channels and receiver channels. The designed PCB board for UAV is shown in Appendix 1. Appendix 2 shows the UAV aircraft designed and mounted in Robotics Lab and used in applications.

CHAPTER VI

Conclusion

In this thesis, the designed controller which is a fuzzy scheduling control system of a quadrotor is proposed. The proposed control scheme is used to control the parameters for the quadrotor flight. These are the altitude and attitude. By achieving these parameters, we control the quadrotor. For this purpose, the kinematics and dynamics of the quadrotor are presented.

Analysis of kinematics and dynamics of robotics show that it has to order nonlinear dynamics and is sensitive to external disturbances. Analysis of the control method demonstrated that one of the efficient methods for quadrotor control is the application of fuzzy logic in control.

Using the Newton-Euler method dynamics of the quadrotor attitude and altitude variables are obtained. Based on the dynamical model the design of PID and fuzzy control system of quadrotor were performed. The unknown parameters such as large disturbances(wind) make PID controller insufficient. The PID controller is sufficient for in near hover mode(without disturbances).

Using dynamic equations the fuzzy scheduling control system structure is proposed. Using proposed fuzzy scheduling control structure design of the control system is implemented. A fuzzy designed controller is aimed to control height, angles of roll, pitch, and yaw.

Functional features of designed control systems are obtained by simulations. Comparison between results is provided to evaluate the how fuzzy scheduling control system is effective. In this way, it is possible to make the controller respond faster to suit the load need. In the theory of control, it is known and popular that complete control can eliminate the error of a solid state. The results obtained demonstrate the efficiency of the non-compliant editing control system. The controller is applied to a quadrotor designed in our research laboratory. The proposed fuzzy scheduling controller used in Matlab 2019, was tested on a real quadrotor and yielded satisfactory results. The RMSE has effects on the results we obtain. As a result of the use of the designed fuzzy scheduling controller, we reduce these effects. Comparison results have been developed to demonstrate the effectiveness of an unconventional planning control system.

To improve the capabilities of controller design we need advancements in dynamics. We need to use more improved and advanced sensors and integrated systems for the improvement of the capabilities of the control system. We can use more hybrid controllers with fuzzy. The neuro-fuzzy model can be used for the control of the quadrotor. With the advancements in sensors, the learning capability of a neural network can deal with the non-linearity of quadrotor dynamics.

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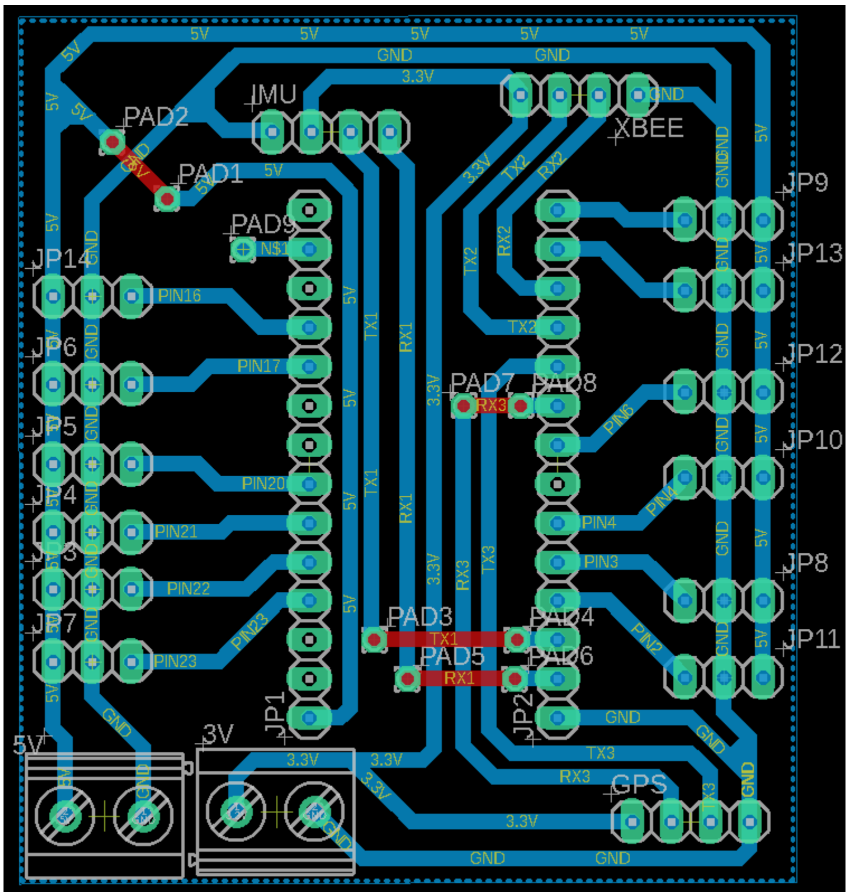
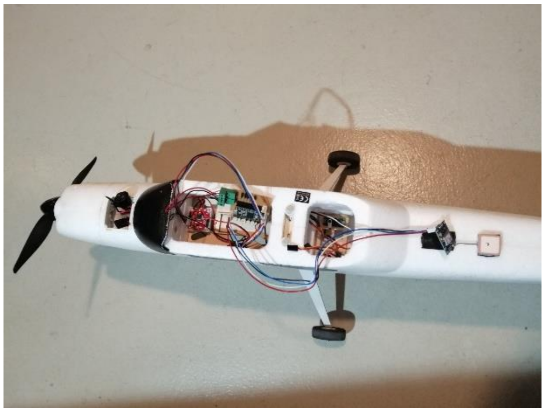
APPENDICES

Appendix 1. PCB Board for UAV



Appendix 2. UAV aircrafts



Appendix 3. Ethical Approval Letter

NEAR EAST UNIVERSITY

ETHICAL APPROVAL DOCUMENT

Date:30/12/2021

To the Institute of Graduate Studies

For the thesis project entitled as “Fuzzy Scheduling Control System Design for Quadrotor”, the researchers declare that they did not collect any data from human/animal or any other subjects. Therefore, this project does not need to go through the ethics committee evaluation.

Title: Assoc. Prof.Dr

Name Surname : Hüseyin Hacı
Signature:

Role in the Research Project: Supervisor