Indian Institute of Technology Kanpur

Department of Aerospace Engineering

AUTONOMOUS UNMANNES AERIAL SYSTEMS - AE630A

Final Exam Report

Biplane Quadrotor Tailsitter UAV

Team
Ahsan Barkati(160055)
Shivank Garg(160658)

Supervisor:
Dr. Mangal Kothari

Contents

1 Acknowledgement

We express our gratitude to Professor Mangal Kothari for providing us the opportunity to work on this project as part of this course. This project has given us the great opportunity to learn the concepts of Control System, VTOL, and Various plane Dynamics. Without his moral and technical support, we would not have been able to complete this effortful task. Overall, we thank him for providing us with the opportunity to make something creative along with gaining.

2 Flight Dynamics Model

The control of Biplane Quadrotor Tail-sitter UAV is governed by regulating thrust of the four variable-pitch rotors in absence of fixed wing control surface. The rotor thrust and torque during hover flight can modeled by blade elemental theory(alongwith momentum theory for inflow calculation)

1. **VTOL/quadrotor mode :** Fixed Wing aerodynamics are ignored. The significant forces acting on the body are thrust and torque from rotor and gravity. (During vertical takeoff, hover, initial transition, and landing phases when no significant aerodynamic forces and moments are generated by the wings)

2. **Transition Mode :** In this mode, the dynamics are considered to be similiar to quadrotor before changing the orientation, and then similar to fixed wing.

3. **Fixed Wing or Forward Flight Mode :** In this mode, we take effect of lift and drag into consideration. The mathematical model of Lift and drag are mentioned in the reference paper and exam paper.

3 Control Objective

1. **Take-off and Landing:** The objective of this mode is to control the vehicle in the quadrotor mode and change the position of the vehicle. This is done by designing a general position controller for the quadrotor mode.

2. **Forward Transition and Back Transition :** The objective of this control is to convert the vehicle mode from quadrotor to the fixed wing mode and vice-versa.

3. **Level Flight :** The level flight is the flight in fixed wing mode. We aim to maintain some steady-state height and velocity.

4 Control Approach

The forward flight is similar to fixed wing mode.

1. **Positional Controller :** It is used in quadrotor mode. In outer loop, we control postion. And, in inner loop, we control attitude. The control design is similiar to the one given in the referenced paper, except the fact that we used Euler angle instead of quanternion.

   Inner Loop: Attitude Controller :

$$\text{Moment } M = -k_R e_R - k_w \dot{e_w}$$

$$e_w = w - R_d R^T w_D$$

$$e_R = (R_d^T R - R^T R_d)^{\vee}$$

   where R is rotational matrix.

   Outer Loop: For the outer loop design, We implemented the same controller given in **A. Quadrotor Mode: 1. Outer Loop Design** in paper: "Biplane-Quadrotor Tail-Sitter UAV: Flight Dynamics and Control by Swati Swarnkar, Hardik Parwana, Mangal Kothari, and Abhishek Abhishek"

2. **TECS :** TECS receives as inputs airspeed and altitude setpoints and outputs a throttle and pitch angle setpoint, which is passed into fixed-wing dynamics model to get output height and velocity. For writing TECS controller, we took reference from PX4 controller diagram and equation - `https://dev.px4.io/v1.9.0/en/flight_stack/controller_diagrams.html#total-energy-control-system-tecs`

   The Total energy of aircraft is given by:

$$E_T = \frac{1}{2} m V_T^2 + mgh$$

   So, we can write specific energy rate by taking derivative and dividing by mgV_T -

$$\dot{E} = \frac{\dot{E_T}}{mgV_T} = \frac{\dot{V_T}}{g} + \frac{\dot{h}}{V_T} = \frac{\dot{V_T}}{g} + sin(\gamma)$$

   For small γ -

$$\dot{E} \approx \frac{\dot{V_T}}{g} + \gamma$$

   So, if T = Thrust and D = Drag force, we can write the following relation -

$$\implies T - D = mg(\frac{\dot{V_T}}{g} + sin(\gamma)) \approx mg(\frac{\dot{V_T}}{g} + \gamma)$$

Change in thrust required:

$$\implies T - D = \Delta T = mg(\frac{\dot{V_T}}{g} + \gamma)$$

Similarly, Specific energy balance rate is given by :

$$\dot{B} = \gamma - \frac{\dot{V_T}}{g}$$

For writing the controller, It is observed that $\Delta T is$ proportional to Specific energy rate, therefore Thrust set-point should be used for total energy control. On the other hand, we see, Elevator control is energy conservative, therfore used to convert PE to KE and vice-versa.

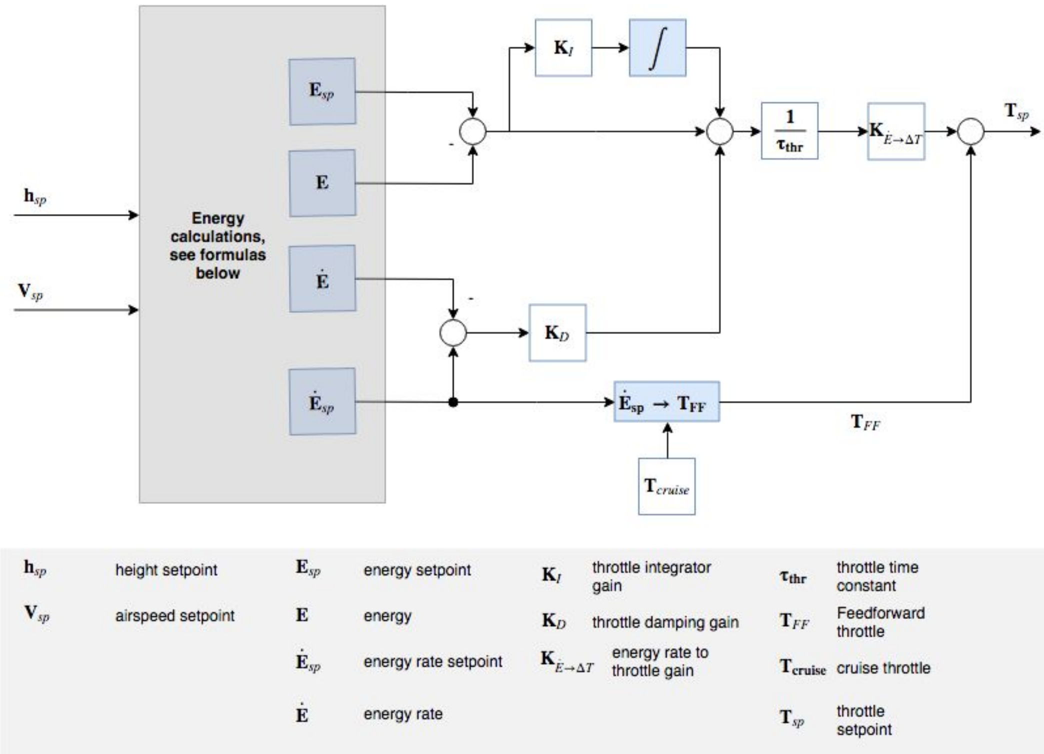

Figure 1: Total energy control loop: Throttle Control

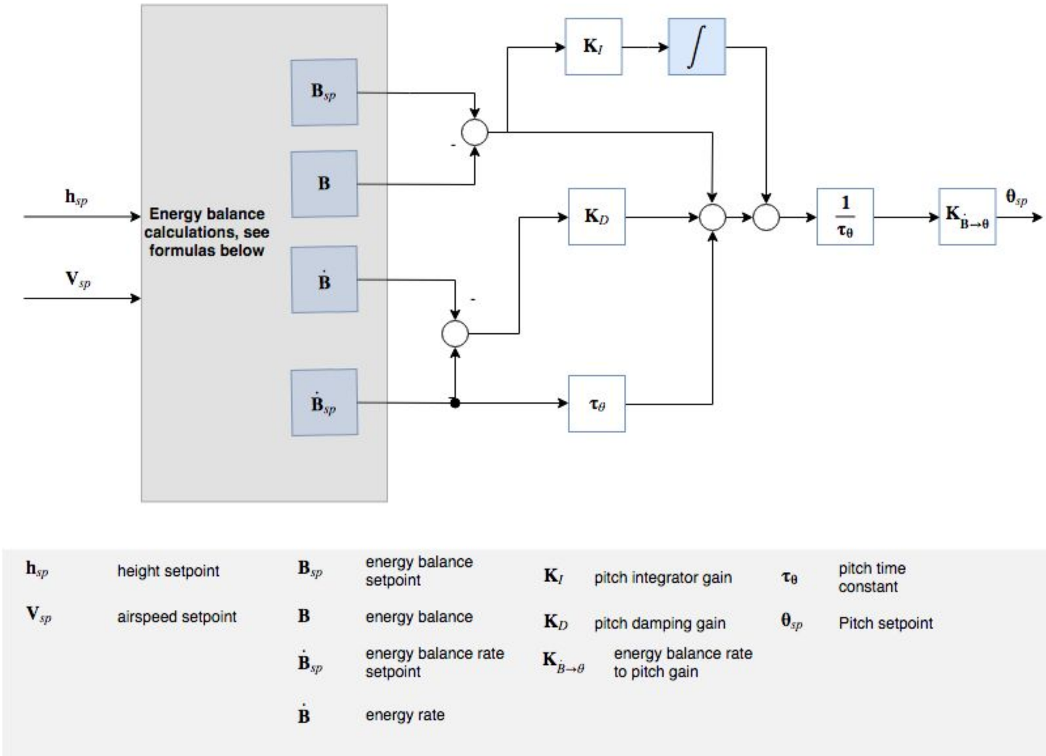

Figure 2: Total energy control loop: Pitch Control

3. **Transition Controller :** In forward transition controller, There are two phases of flight control. In First phase, The Aircraft operates in the quadrotor mode. So, During transition, we take the aircraft to an intermediate pitch angle, $\theta_{inter} =$ Stall Angle $+ \gamma_d - \pi/2$. Aircraft is at this pitch angle for sufficient time to gain velocity for forward flight mode. Then comes the second phase. In second phase, the aircraft control is handed over to TECS controller.

   In Backward forward transition controller, The aircraft is assumed to be operated in forward flight mode first with target velocity set to zero. We give a guided pitch angle as $\theta_c = \kappa(\pi/2 - \theta)$, κ is a constant. So, we make the target pitch angle to $\pi/2$, while slowing down the throttle. This decreases the velocity, and increase the potential energy of aircraft. When aircraft become vertical, the vehicle starts to operates in quadrotor mode and give control to our positional controller again.

5 Simulation Results

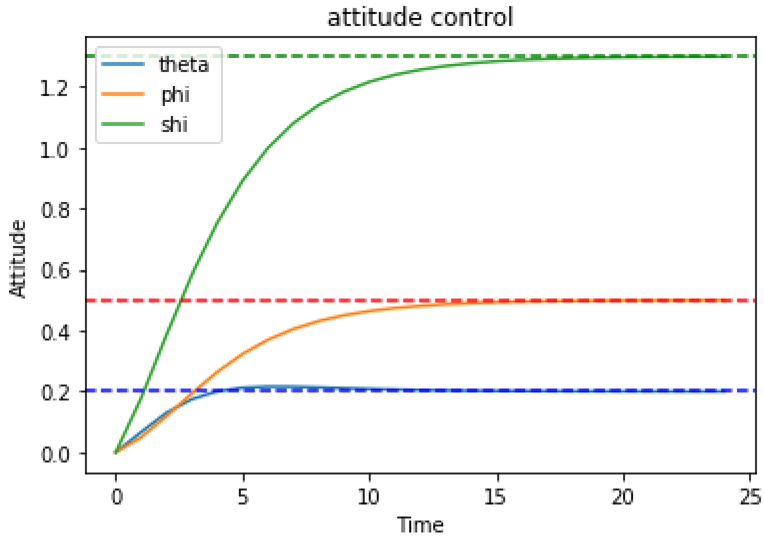

Figure 3: Attitude Controller

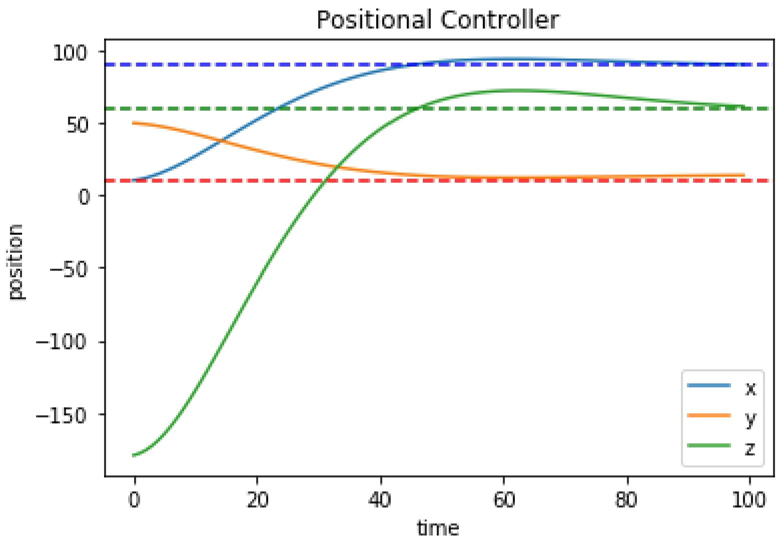

Figure 4: Position v/s time

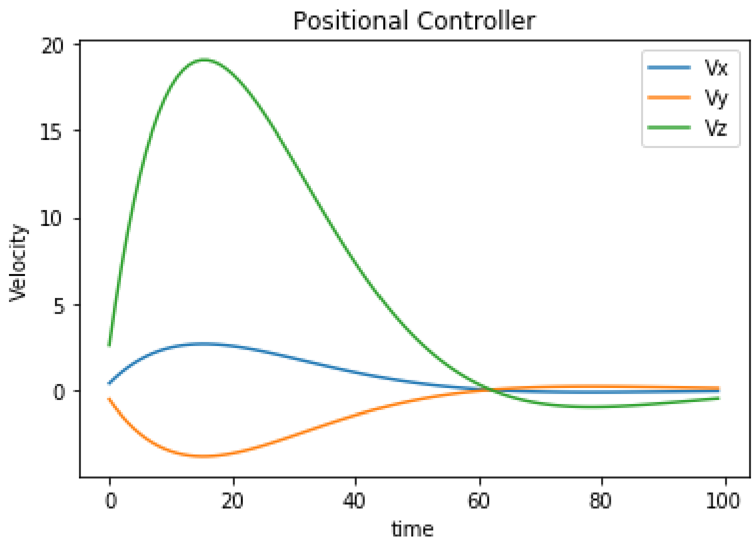

Figure 5: Velocity v/s time

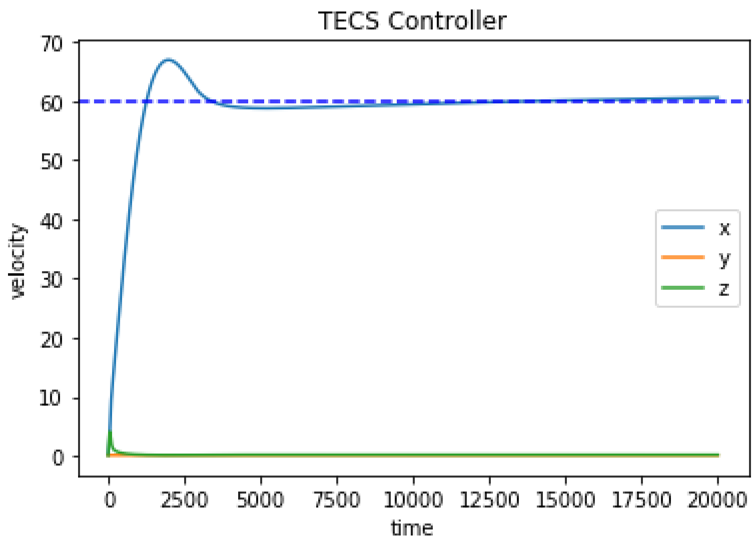

Figure 7: Velocity v/s time

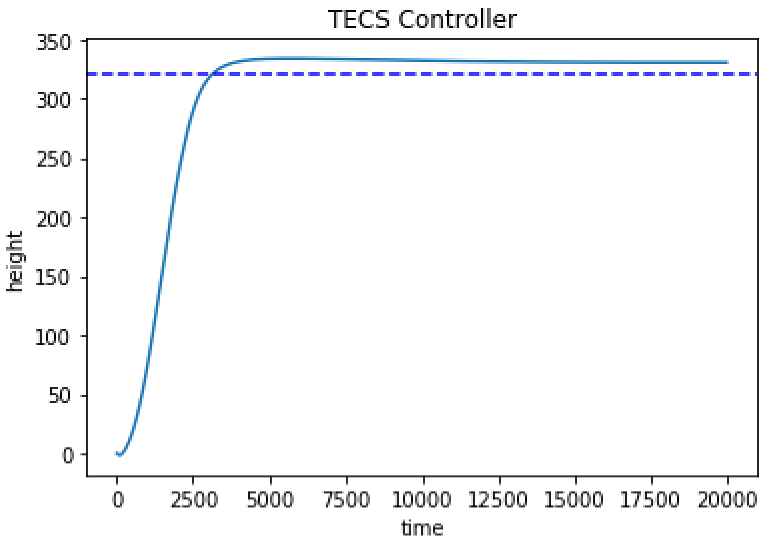

Figure 6: Height v/s time

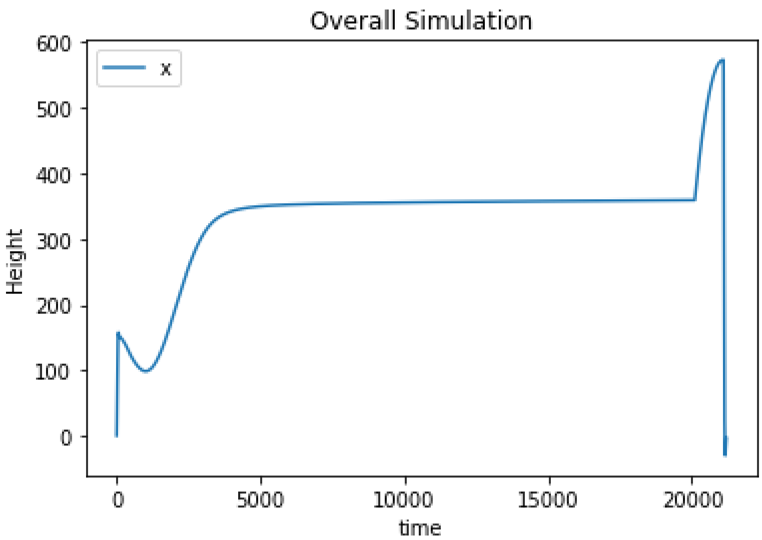

Figure 8: Full Envelope height simulation

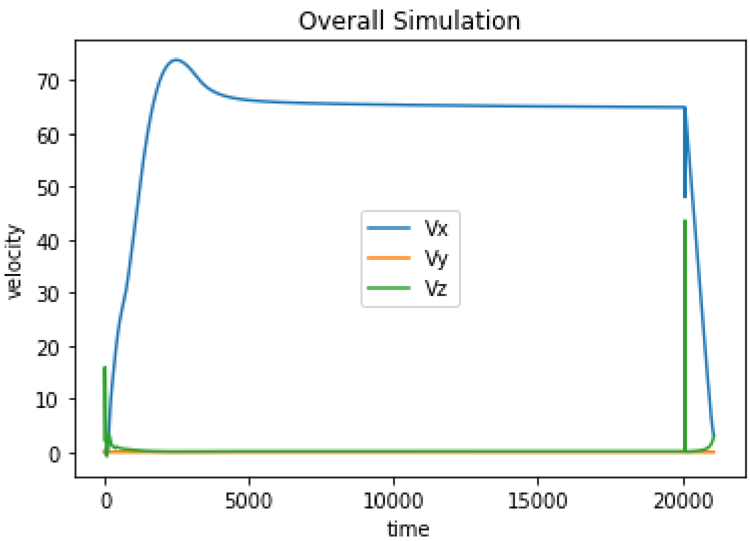

Figure 9: Full envelope Velocity simulation

6 References

1. For Flight Dynamics Model : Biplane-Quadrotor Tail-Sitter UAV: Flight Dynamics and Control by Swati Swarnkar, Hardik Parwana, Mangal Kothari, and Abhishek Abhishek

2. For TECS positional controller in Fixed wing: PX4 Controller Diagrams

3. TECS other references: Nonlinear Total Energy Control for the Longitudinal dynamics of an aircraft by Matthew E. ArgyleRandal W. BeardRandal W. Beard