Design a Robust RST Controller for Stabilization of a Tri-Copter UAV

1. Zain Anwar Ali, 2. Dao Bo Wang, 3. Muhammad Aamir

1&2. College of Automation Engineering Department, Nanjing University of Aeronautics & Astronautics, Nanjing, China
3. Sir Syed University of Engineering & Technology Karachi, Pakistan.
E-mail: zainanwar86@hotmail.com,

ABSTRACT

Research on the tri-rotor aerial robot is due to extra efficiency over other UAV's regarding stability, power and size requirements. We require a controller to achieve 6-Degree Of Freedom (DOF), for such purpose, we propose the RST controller to operate our tri-copter model. A MIMO model of a tri-copter aerial robot is challenged in the area of control engineering. Nine states of output control dynamics are treated individually. We designed dynamic controllers to stabilize the parameters of an UAV. The resulting system control algorithm is capable of stabilizing our UAV to perform numerous operations autonomously. The estimation and simulation implemented in MATLAB, Simulink to verify the results. All real flight test results are presented to prove the success of the planned control structure.

Key-Words: Unmanned Vehicle, Tri-copter Controlling, Dynamically Controlling, RST (Regulation, Pole Placement & Tracking)

1. INTRODUCTION

The UAVs (Unmanned Aerial Vehicles) is the flying vehicles

without pilot, which have seen rapid growth in military surveillance and civilian rescue operations during the last decades.UAVs have been developed in a wide variety of shapes, sizes, configurations, and characteristics. The development of UAVs, began in the early 1900's, and the technology in its early stages was used by the military due in World War I and expanded by World War II [6]. For the development of the UAVS it is necessary to have a variety of knowledge, including aeronautics, autonomous control, and signal processing and different types of sensors. There are numerous necessities for UAVs used in such areas, Such as the UAV must be small, sized quick movements so that it could avoid a sudden collision, have vertical takeoff and landing ability, and also in sudden directional turns.

To fulfill all the above necessities, a multi-rotor thrust UAV is the best solution for this [2]. The growing recognition of the potential of using UAVs for search and rescue applications is supported by an increasing number of works in the areas of image recognition for victim detection, path planning and task allocation [3-4].

Different types of multi-rotor have been developed include such as Bi-copter, Tri-copter, Quad-copter as well as hex-copter and conventional rotor craft and helicopters. In this research our main concern is Tri-rotor Vehicle and also called as Tri-copter. Tri-copter has three motor systems and is less-expensive and has more flexibility.

One clear advantage of a Tri-rotor over a quad-rotor is that It requires one less motor, leading to a reduction in weight, Volume and energy consumption [5]. As compared to quad-rotors have a longer flight time due to a reduction in the number of motors. Smaller in size and low cost makes it ideal for deployment in various military and civil research missions. In

general, tilt rotor configuration is used to control the forces on the horizontal and only one tail rotor has an ability to control the yaw moment. Tri-rotor vehicles Dynamics are extremely coupled and nonlinear, the development of controller design for such vehicles is the key problem for successful flight and operations. Many researchers have been addressing control design problems for VTOLs in order to accomplish a higher accuracy and robustness given in the presence of model uncertainties and disturbances. Numerous types of control techniques have been developed such as the discrete PID controller, a linear, quadratic regulator (LQR) method to control.

Robust adaptive and back stepping control methods were proposed and validated experimentally on a quad rotor. Although the control methods used in different manuscript and work effectively. But the structure of controller parameters adjustment is complicated. So adaptability and robustness of the controllers are imperfect. Therefore, emerging a controller for the tri-rotor with modest structure, simple way to tuning parameters and decent adaptability is important. For stabilizing the UAV in this research, we use the RST robust controller. The actuators of tri-copter are controlled by the servo motor. The major forces reacts on the vehicle are produced by the propeller that can handle the controlling of yaw, pitch, roll and altitude of the aerial vehicle. The Euler angles of elevation and velocities have been controlled by a Robust RST controller method. The division of this paper which is divided into 5 sections. In section 2 equations of motions of the tri-copter vehicle is defined along with its dynamics. In the section 3 & 4, the Engine model and the designing a control strategy to control the parameters is defined. Moreover, the simulation and results are shown in section 5.

2. EQUATION OF MOTIONS& DYNAMICS OF TRI-ROTOR VEHICLE.

To develop the model of the tri-copter which is derived by using Newton-Euler Formulation. The vehicle is described using a right hand, the generalizedthe earth coordinatethe system of axes and the right hand body frame. Positive x-axis points towards the front rotors (rotors 1 and 2), positive y-axis points towards the right (rotor 2), and positive z-axis is directed downwards. The Positive sense of three angular variables Roll (ϕ), Pitch (θ), and Yaw (ψ) is decided by a right-handed rotation about positive x, y, and $z$axes, respectively [1]. The tilt angle $\mu$is measured by y-$z$coordinate axis. The dynamic modeling suggested of the triple tilting rotor.

The UAV is introduced based on Newton-Euler mathematical formulation, which has six degrees of freedom (DOF) and four inputs: three speeds of watercraft and one tilt angle. Following the conventional helicopter control commands, tri-rotor UAVs have similar commands, which are collective, lateral, longitudinal, and yaw or pedal [2]. They are indicated as δ col, δlat (Roll control), δl on (Pitch control), and δPed (Yaw control). Since two front rotors operateat different speeds, they generate Roll (ϕ) control, for example, when the speed of rotor 1 is up and that of the rotor 2 down, and make the UAV toward the right and vice versa. The Pitch (θ) control is created as the third tail rotor changes velocity. The achievement Yaw (ψ) control occurs by varying the tilt angle μ.

The nonlinear equations of motion of conventional UAVs, which have 6 DOFs, are also used for tri-rotor UAVs. The designed model is free to rotate and translate of3Dspace [2].

Aero Dynamic Equations

Force Equations

$$X = M(\dot{U} + QW - RV) + MG\,SIN\Theta \quad (1)$$
$$Y = M(\dot{V} + RU - PW) - MG\,COS\Theta\,SIN\Phi \quad (2)$$
$$Z = M(\dot{W} + PV - QU) - MG\,COS\Theta\,COS\Phi \quad (3)$$

Moments Equations

$$L - I_x\dot{P} = I_{xz}\dot{R} + QR\,(I_z - I_Y) - I_{xz}PQ \quad (4)$$
$$M - I_Y\dot{Q} = +RP\,(I_x - I_z) + I_{xz}\,(P^2 - R^2) \quad (5)$$
$$N + I_{xz}\dot{P} = +I_z\dot{R} + PQ\,(I_Y - I_x) + I_{xz}QR \quad (6)$$

Angular Rates

$$P - \dot{\Phi} = -\dot{\Psi}SIN\Theta \quad (7)$$
$$Q - \dot{\Theta}\,COS\Phi = \dot{\Psi}COS\Theta\,SIN\Phi \quad (8)$$
$$R - \dot{\Psi}\,COS\Theta\,COS\Phi = -\dot{\Theta}\,SIN\Phi \quad (9)$$
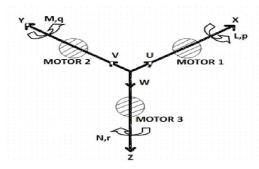

Fig 1: 120-degree Phase Typical Diagram of Tri-Rotor Vehicle.

Euler angles and velocities

$$\dot{\Theta} = Q\,COS\Phi - R\,SIN\Theta \quad (10)$$
$$\dot{\Phi} = P + Q\,SIN\Phi\,TAN\Theta + R\,COS\Phi\,TAN\Theta \quad (11)$$
$$\dot{\Psi} = (Q\,SIN\Phi + R\,COS\Phi)\,SEC\Theta \quad (12)$$

3. THE MAIN ENGINE MODEL OF TRI-COPTER

A permanent DC servo motor is a very useful factor in most of the real time control systems in modern UAVS. Where the motor input signal relates to the armature voltage VA(t) depends upon the time, and output signal relates to the angular position θ (t), where Ra is the resistance and La is the inductance of the armature winding in the motor. The angular rotation responsible to generate the back EMF (Vb) and inertia or load of the motor (J) and where a damping factor is B.
The equations of the electrical system are as follows.

$$V_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + V_b(t) \qquad (13)$$

Equation (13) Along with equation (14)

$$V_b(t) = K_b \frac{d\theta(t)}{dt} \qquad (14)$$

$$V_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + K_b \frac{d\theta(t)}{dt} \qquad (15)$$

Where K_b is the motor back EMF constant. The equation for the mechanical side system is defined as below.

$$\frac{d^2\theta(t)}{dt^2} + B\frac{d\theta(t)}{dt} = T_{app}(t) \qquad (16)$$

$$T_{app}(t) = K_{Ti_a}(t) \qquad (17)$$

$$J\frac{d^2\theta(t)}{dt^2} + B\frac{d\theta(t)}{dt} = K_{Ti_a}(t) \qquad (18)$$

Where $T_{app}(t)$ is the applied torque, and K_T is the torque constant that relates the torque to the armature current.

Some pros of the servo motor are as follows.

- *The speed of operation of a servo motor is defined as the required time for the shaft to reach a specified position. Common servos have operating speeds in the range of 0.05 to 0.2 s/60 degree*
- *Typical values of torques of servo motors are in the range of 0.5 to 10 kg/cm.*
- *This characteristic is important in the mechanical design of projects. Typical RC servo motors have a weight range between 15 and 200g [7].*

4. DESIGNING A CONTROL STRATEGY TO CONTROL THE PARAMETERS.

We have used an RST controller with the zero cancellation to gain an optimal-desired response from an actual response. The actual response is given in the equation (a).

$$G_{\theta,\emptyset,\varphi} \;=\; \frac{B_m(q)}{A_m(q)} \tag{19}$$

Translational and Rotational movement Control Implementation of the RST controller for achieving the desired response is a key feature of our algorithm through which we can control the dynamics of the tri-copter. Poles of our actual system are 3 and zeros are 2, through which we can identify the order of the controls. The equation (20) is used to identify the order of the controller,

$$Ac = 2*\deg A - 1 \tag{20}$$

This shows that Controller must be 2nd ordered. The Degree of RST must be the 2nd order. We used a zero cancellation approach to achieve our desired response. So the degree of Ao is found to be zero.

4" R- = for pole zero cancellation,

$degAo = degA - degB^+ - 1$

So taking,
Ao = 1

The Diophantine equation is stated in the equation (21),

$$Ao*Am = A R^- + B^-(S) \quad (21)$$

$$\therefore S = s_0 q^2 + s_1 q + s_2 \quad (22)$$

$$T = \frac{Bm(Z)}{B^-} \quad (23)$$

$$U(t) = \frac{T}{R} Uc(t) - \frac{S}{R} y(t) \quad (24)$$

Equation (24) represent the control law for controlling the desired parameters i.e., Yaw Pitch and roll.

5.   SIMULATION RESULTS

Here we simulate the control algorithm for the tri-copter model using an RST controller by applying robust technique. We assume all the initial conditions are zero and the desired system response within the stable limits.
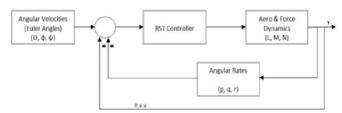

Fig 2: Close Loop Control Diagram.

For vertical takeoff and landing all angles of pitch and roll remains zero and the 3D orientation of the rotational subsystem must under the desired state. The proposed control system is responsible for compensating the initial errors by maintaining the fly dynamics to the desired value accordingly.

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The Control signal is also shown in Fig 4, but the control algorithm adopts the change in input and stabilizes the output.
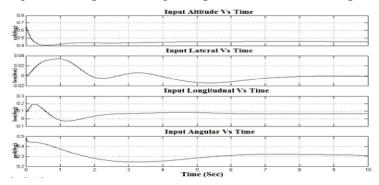

Fig 3: The Desired step response and controller output of the System.

First, we are applying RST method to both responses using T/R and S/R with step input by referring it to the general equation of the RST controller. In input vs. discrete output diagram, the system is stable and as well as the tri-copter flies the variation in the response of the system due to variation in the dynamics is controlled shown in the desired step output.

Given the image of Angular rate, Euler angle and Transitional velocity represent the output of our system. It displays certain changes occurs during flight and thus tends to maintain its state according to the given coordinates
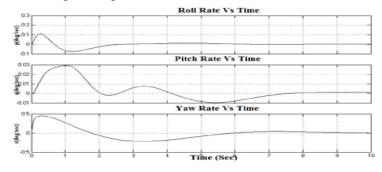

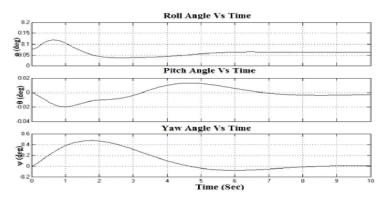Fig 4: Desired Angular Rate responses of tri-copter.

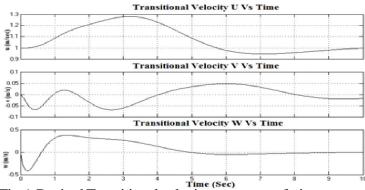Fig 5: Desired Euler angle responses of tri-copter.

Fig 6: Desired Transitional velocity responses of tri-copter.

Now the air dynamics of the tri-copter is also stable as shown in fig 4, 5, 6. The variation in each angle (covering one dynamic) and desired responses of dynamics is controlled by the controller where the initial overshoot is detected and tends to minimize this, the robust technique is used using RST model. Mathematical model represented earlier shows 2nd order controller. The transitional components of the tri-copter is depend upon the (u,v,w), (p, q, r) and (θ, φ, ψ) dynamics and these dynamics are controlled individually with separate control blocks implemented on MATLAB using RST model. The time derivative of the regular variation is independent of the transitional components due to 6-DOF equations controlling the tri-copter.

6. REAL TIME APPLICATIONS

The real time application of the system include many areas but in this research we are focused on three major applications like making maps of the city,disaster management and in media coverage.The Asian foundation in China firstly used UAV's for the collection of high quality images and elevation data for the city. These high quality images were used to create detailed maps with elevation data, labeled neighborhoods, roads, buildings, and other features. On the other hand UAV is used to collect the data of Hurricane Katrina in 2005 at Gulf Coast. More-over UAVs is used first time by Chinese media for news reporting and also used for sports shooting a Chinese website (http://www.hysport.tv) focusing on cycling news and cycling race broadcasting. They are using UAVs to cover cycling race live broadcasting [8].

7. CONCLUSION

A robust technique by applying RST controller is used to stabilize througha linear control system for the tri-copter. The control strategy for control, dynamics such astranslational and rotational movement mathematically proposed a model for stabilizing. The related angles for stabilization are controlled mathematically. The mathematical proposed system is capable to perform according to given parameters. All simulations and results are synchronized and perfectly linked together. Our system is applicable in almost all rigid environments. The real time applications include disaster management and monitoring as well as media coverage.

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