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Comparative Analysis of Tri-rotor & Quad-rotor UAV

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ABSTRACT

The goal of our research is to create a UAV for both non-military and military purposes that do not need a runway for takeoff and can be efficiently used for surveillance, search and rescue operations and spying .Through UAV manpower will reduce and verity of application can be performed.We comparatively analysis the design, control portion, and dynamics of two different UAVs one is tri-rotor and another is quad-rotor. In Tri-rotor three rotors are on samedistance from its center. Contrary to a Quad-rotor, in Tri-rotor the rotorsproduce a unstable reaction torque in system due to this characteristic it become challenging in modeling, stability and control of tri-rotor.

Keywords: Quad-rotor,Tri-rotor, UAV.

INTRODUCTION

In the last decades the use of Unmanned Aerial Vehicles (UAV) has increased due to the development and improvement of control systems [1].Due to their applications and enormous potential in the field of military. There are a few situations where a civilian could not perform his work properly, i-e (working in sloppy terrains, demolishedsites, areas of military operations, or Indoor facilities). Since working in these areas does not require a lot of machinery, suitable solutions are required. In order to work in these difficult situations, Unmanned Aerial Vehicles (UAVs) have been deduced as the best solution as compared to the logic that came before it.Unmanned Aerial Vehicles (UAVs) can provide a critical support to search and rescue operations due to their high speed [5].UAVs are primarily used to gather intelligence and provide a surveillance and reconnaissance function for the armed forces. Only a handful of systems are capable of carrying weapons[6].For more efficiency in term ofsize, autonomy, maneuvering and other factors, some conventional and non-conventional designs, configurations and controlling techniques for UAV systems have been proposed. Some necessary requirements that a UAV must possess are:

- Small size in order to guarantee free movement under any situation.
- Quick motion in every direction for evading obstacles.
- To be developed as cheaply as possible

- Should not require a runway to take off.(i.e. like a helicopter)

To be able to satisfy the above requirements, a multiple rotor thrust UAV is learned to be the best solution.

Mini and micro UAVs are very heightened and productive platforms for security and monitoring applications for outdoor and in-door environments. Micro UAV's are between 0.1-0.5 meters in length and 0.1-0.5 kilogram in weight [7]. The limited payload for carrying sensors and the computational power on-board make the development of autonomous UAVs very challenging.

MATERIALS AND METHOD

Design ofthe Structure:

A multicopter is a rotorcraft that has more than two rotors, in light of the fact that a rotorcraft with two rotors is called helicopter (bicopter) [4]. There are various kinds of Multi-rotor UAVs which includes bi-rotor, tri-rotor, quad-rotor, and also the helicopter. All these systems have something to givein exchange for some drawbacks. The popular structures of the modern UAV's are as follows.

Quad-Rotor

The primary designs of a multi-rotor include a Quad-rotor. It has an easy structure, but difficult dynamics. A quad copter is a device with four propellers arranged in a cross configuration. Two propellers spin clockwise and two counter-clockwise, which lifts the quad copterintotheairwhile avoiding anyNet angular momentum [2]. The net aerodynamic torque and the angular acceleration in the yaw axis is zero. Yaw is induced by dis-balancing in aerodynamic torques. Roll or pitch is introduced in by increasing or decreasing speed of one of the rotors. By managing the speed of the four motors, takeoff, hovering landing and other movement can be achieved.

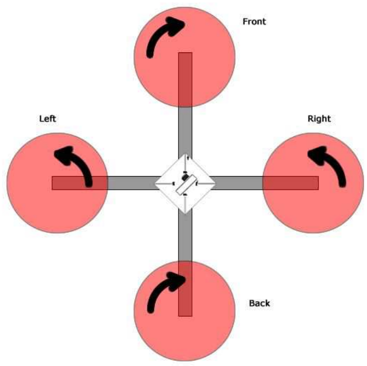


Fig 1: Diagram of Quad- copter UAV

General quad-rotor UAVs has less flexibility in movement because of its possessing under-actuation, i.e., availability of 4 not dependent inputs in control (the velocities of four propellers) vs. the quad-rotors co-ordinates in space. As a result, the 6 DOFs describing the parameters of the quad-rotor pose would not track any specific trajectory in time (e.g., it can hover on that position only whenit's horizontal).

TRI-ROTOR

Tri-rotors are more efficient compared to quad-rotors with respect to the size and the requirement of power, smaller in size, easier to understand, cheaper and have better time of flight because of three rotors decrease in the number of motors, but Tri-rotor are more challenging in terms of stability and control.

Tri-rotor vehicles are vehicles with a triple rotors arrangement in a Y or T shape. This structure gives it more mobility and higher speed. All three blades of tri-rotors are same in length and the 3 force inducing parameters are also same. Each force inducing parameters includes a fixpropeller for pitch moved by a Brushless DC (BLDC) motor to produce thrust. The propeller-motor is attached to the arm of body by a servo motor that can spin in a vertical axis to tilt the motor of the propeller to produce a horizontal component of the produced force. All 3 propellers can be tilted independently to provide full authority of vectoring in thrust. This tuning makes the body of the vehicle capable of staying straight in its required direction regardless of the movement it makes.

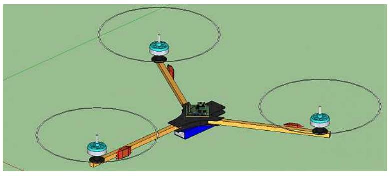


Fig 2: Diagram of Tri- copter UAV

The problem faced by the tri-rotor UAV is having a yaw moment that is generated by the reaction torque from the unpaired rotor. To solve this problem, a few designs of tri-rotor UAV have been developed each with their own solutions. Two of those designs are:

Control Techniques:

Unmanned Aerial Vehicles have steady nonlinear dynamics. A few timesin control theory it is possible to linearize such systems and apply linear techniques, but in many situations it becomes necessary to devise theories from scratch permitting control of nonlinear systems.

$$u = a(x) + b(x)v$$

PID Control:

PID controller i.e. Proportional Integral derivative Controller is a basic controller system technique used by experts as well as amateurs in the field. The algorithm is based on thefollowing equation.

$$\mathrm{u}(t) = \mathrm{MV}(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau - K_d \frac{d}{dt} e(t)$$

The important factors of this equation are the K_p, K_i and K_d which are multiplied with the error. They are called the Proportional gain, Differential gain and the Integral gain respectively. Their values are varied to produce a response in error without overshoot with-in the required time. In the absence of any knowledge of the underlying process, a PID controller has generally been considered the best controller. Though in the presence of the actual model the optimized values can be achieved, otherwise the values are achieved by trial and hit with no proof optimization.

LQ Control:

Linear Quadratic control also known as LQ control is used in multiple input systems where the feedback gains, given that a set of desired Eigen values are not rare. Linear Quadratic (LQ) optimal control does not specify the closed loop Eigen values exactly, but instead specifies some kind of performance objective function that needs to be optimized.

The LQ model-based methods could be divided into two different methods. First of them is the LQR (Linear Quadratic Regulator) method. This design method supposes an available for the measurements of state variables of the control system. This problem is called "full state feedback" problem. The second LQ design method is the LQG (Linear Quadratic Gaussian). This method gives consideration of the influence of internal and external stochastic disturbances affecting motion of the aircraft.

Back stepping Control

In control theory, back stepping is a technique developed circa 1990 byPetar V. Kokotovic and others [8], for designing stabilizing controls for a special class of nonlinear dynamical systems. These systems are built from subsystems that radiate out from an irreducible subsystem that can be stabilized using some other method. Because of this recursive structure, the designer can start the design process at the known-stable system and "back out" new controllers that progressively stabilize each outer subsystem. The process terminates when the final external control is reached. Hence, this process is known as back stepping [9].

Feedback Linearization Control

Another common approach used in controlling nonlinear systems is Feedback linearization. The approach includes coming up with a transformation of the nonlinear system into an equivalent linear system by changing of variables and a suitable control input. Feedback linearization may be applied to nonlinear systems of the form.

$$\dot{x} = f(x) + g(x)u$$

$$y = h(x)$$

The goal is to make a control input that renders a linear input–output map between the new input v and the output. An outer-loop control strategy for the resulting linear control system can then be applied.

Accelerometer:

The accelerometer is a built-in electronic component that measures motion and tilt. It is also capable of detecting motion and rotation gestures such as shaking and swinging. Accelerometer is reliable under static conditions as it does not include any integral terms to accumulate the error. In dynamic conditions the gyroscope readings are very reliable so their weight is increased in the final equation. In static conditions error is accumulated in its readings so its weight is minimized in the final equation.

Lift:

The lift is produced by the flaps in the wings of the UAV. Flaps are control surfaces attached to the wings of the air-plane. In this UAV the wings are acting as the flaps and their movement is controlled by the servo motors. When they moved downwards the direction of the reaction force is upwards so it produces a lift on the UAV. Both the flaps move simultaneously. They are used to increase the lift at low speed.

Roll:

The roll mechanism in the air-plane is controlled by the ailerons which are control surfaces attached at the end of the wings of the UAV. The force is applied to both the ailerons are differential in nature. They move in pair and produce a couple. They are not attached near the main body of the UAV because that would make them be near the center of gravity and moment arm will become less so a very large force would be required to produce the same measure of torque as it was when it was attached at the end.

Pitch:

Elevators are flight control surfaces, usually at the back of an aircraft, that controls the air-plane's longitudinal altitude by changing its pitch balance, and also the angle of attack and the lift of the wing. Just like flaps they move in a pair simultaneously.

Yaw:

On an airplane the rudder is used primarily to counter yaw. In normal form, a rudder is a flat plane or sheet of material attached to the craft's tail by hinges, often shaped so as to minimize aerodynamic drag. In this UAV the yaw mechanism is controlled by using the front motors that are attached at the end of both wings, and not by a usual rudder. By controlling the speed of front motors the yaw movement will be provided. The speeds of the motors are changed differentially.

Sensors:

The sensor which is used in this UAV is IMU (Inertial measurement Unit) FreeIMU 0.3.5 BMP. An IMU works by detecting the current rate of acceleration using one or more accelerometers, and detects changes in rotational attributes like pitch, roll and yaw using one or more gyroscopes and magnetometers which allows good performance for dynamic orientation calculation.

- ITG3205 3-axis gyro
- BMA180 3-axis accelerometer
- HMC5883L 3-axis magnetometer

The final reading of IMU is a weighted sum of the readings of these three sensors. 50 readings per second are taken from the IMU used in this UAV. The final equation which it implements is:

IMU= gyroscope + accelerometer + magnetometer

In this UAV magnetometer readings are not taken because our yaw mechanism is controlled manually and PID algorithm is not implemented on it.

RESULTS AND DISCUSSION

- **Simulation of Quad:**

Angular Rates,

$P = \Phi - \Psi \sin\Theta Q = \Theta \cos\varphi + \Psi \cos\Theta \sin\Phi$

$R = \Psi \cos\Theta \cos\Phi - \Theta \sin\Phi$

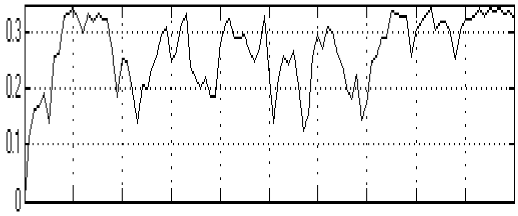
Euler angles and body angular velocities,

$\dot{\theta} = Q\cos\Phi - R\sin\Theta$

$\dot{\varphi} = P + Q\sin\Phi \tan\Theta + R\cos\Phi \tan\Theta$

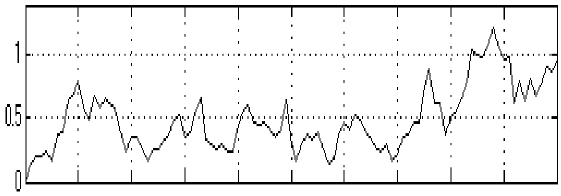
$\dot{\psi} = (Q\sin\Phi + R\cos\Phi) \sec\Theta$

In the following Figures yaw, pitch and roll rates are given that are constantly changing over time as does the movement of designed vehicle.



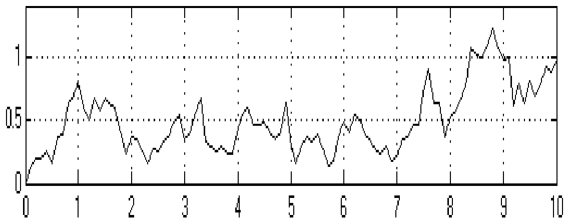
Time (sec)

Fig 3(a): Diagram shows Pitch of Quadrotor (Amplitude Vs Time)



Time (sec)

Fig 3(b): Diagram shows Yaw of Quad rotor (Amplitude Vs Time)



Time (sec)

Fig 3(c): Diagram shows Roll of Quad rotor (Amplitude Vs Time)

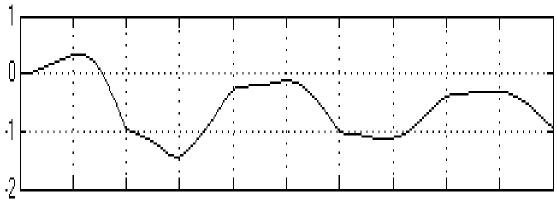
- **Simulation of Tri-rotor:**

Angular Rates,

$$p = \dot{\phi} - \dot{\psi}\sin\theta$$
$$q = \dot{\theta}\cos\varphi + \dot{\psi}\cos\theta\sin\varphi$$
$$r = \dot{\psi}\cos\theta\cos\varphi - \dot{\theta}\sin\varphi$$

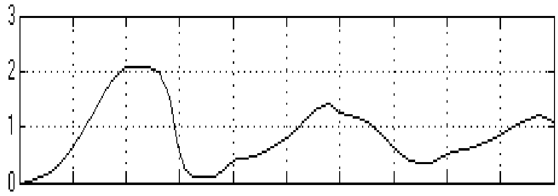
Euler angles and body angular velocities,

$$\dot{\theta} = q\cos\varphi - r\sin\theta$$
$$\dot{\varphi} = p + q\sin\varphi\tan\theta + r\cos\varphi\tan\theta$$
$$\dot{\psi} = (q\sin\varphi + r\cos\varphi)\sec\theta$$



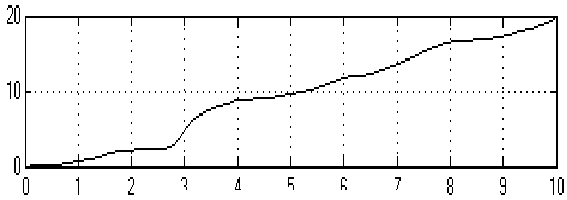
Time (sec)

Fig 4(a): Diagram shows Pitch of Tri rotor (Amplitude Vs Time)



Time (sec)

Fig 4(b): Diagram shows Yaw of Tri rotor (Amplitude Vs Time)



Time (sec)

Fig 4(c): Diagram shows Roll of Tri rotor (Amplitude Vs Time)

- **LQR Responses of Quad Rotor & Tri Rotor.**

But in this paper our proposed controller is LQR and all the results below shown in the proposed choose controller.

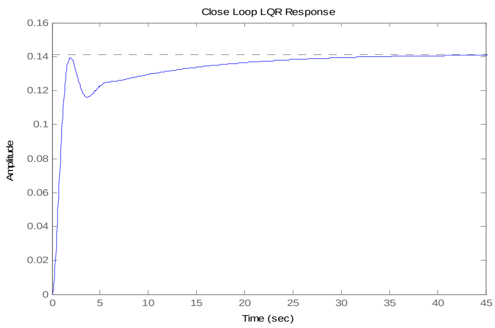


Fig 5(a): Diagram shows LQR Response of Quad rotor (Amplitude Vs Time)

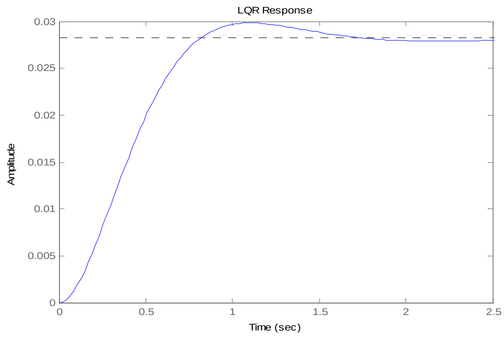


Fig 5(b): Diagram shows LQR Response of Tri rotor (Amplitude Vs Time)

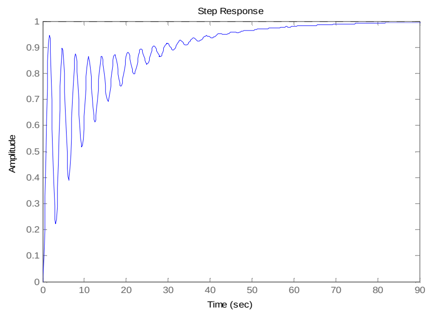


Fig 5(c): Diagram shows Step-Response of Quad rotor (Amplitude Vs Time)

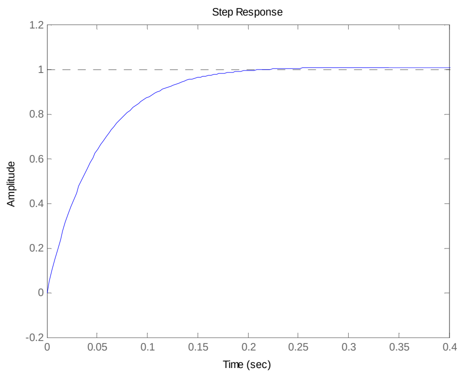


Fig 5(d): Diagram shows Step-Response of Tri rotor (Amplitude Vs Time)

CONCLUSION

We have stabilize the control of UAVs by LQR method and input equations and also show the LQR response of Tri-rotor & Quad-rotor .Finally we have succeed to achieve stabilization of roll,pitch & yaw. Stabilization test for each parameter was conducted individually and further stabilization is achieved by changing gain of Controller. All practical and computer simulations aresuccessfully completed and got our goal to self-stabilize the UAV under all circumstances.

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