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Quadcopter Flight Dynamics

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Abstract: quadcopter are miniature, high power robots that are capable of flying with the help of a remote control system. These robots draw inspiration from bees in the biological system. These robots are designed like a mini helicopter, based on the quad rotor design. Fr swan x1 is a popular flying robot used as an unmanned arial vehicle (uav). The design of the flying drone consists of the quad rotor with four propelling wings. Out of the four motors, the left and right induce pull action, while the front and back induce push action.the brain of the robot is a microcontroller board that has been designed for auto-piloting drones.the microcontroller is combined with an inertial measurement unit. This unit consists of a 3 axis gyro, 3 axis accelerometer and a barometric pressure gauge.an rc transmitter is used to navigate the robot. Functionalities of the robot can be enhanced further by fitting a gps chip for gauging latitude and longitude and a sonar system for gauging the altitude.
Keywords : altitude, quadcopter, hover, land, uav, orientation, pitch, roll, rotor, rpm, takeoff, thrust, velocity

I. INTRODUCTION

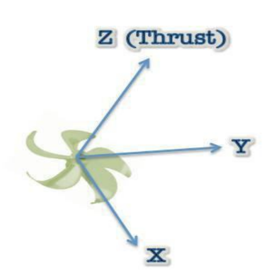
A quadcopter is a popular form of UAV (Unmanned aerial vehicle). It is operated by varying the spin RPM of its four rotors to control lift and torque. The thrust from the rotors plays a key role in maneuvering and keeping the copter airborne.Quadcopters are small in size and flying manoeuvrability enables the user to perform flying routines which includes complex aerial maneuvers . But to do this a certain handling of the copter is must .The perfect handling is fundamental to fly by certain user – define length trajectory-base path and can be done while performing any type of missions. This paper serves as a solution to handling the quadcopter with angular precision by illustrating how the spin of the four rotors should be varied simultaneously to achieve correct angular orientation along with standard flight operations such as taking-o , landing and hovering at an altitude

II. CONTROLLING OF QUADCOPTER

A particular controller in the joystick is used to adjust the altitude. When the controller is moved up or down, the propeller speed is adjusted causing the quadcopter to gain or lose altitude. This feature is used for taking-off/landing or fixing altitude while airborne. Another controller is used to control the pitch/roll or angle of the quadcopter enabling it to move forward/back and left/right. Moving the controller to a certain direction increases the speed of the propellers in opposite relation to the direction the controller is pushed. For instance, if the controller is pushed right, the left side propellers will speed up to tilt the quadcopter and cause it to move to the right. The copter‘wor are used interchangeably throughout the paper. It give yougive mathematical perspective of the aforementioned copter behaviors.

III. INERTIAL AND BODY FRAME

The inertial frame is defined with respect to the ground, with gravity pointing in the negative Z-axis. (Fig. 2) The body frame is defined by the orientation of the quadcopter, with the rotor pointing in the positive Z-axis and the arm-extensions pointing in the positive/negative X and Y axes. (Fig. 1) All metrics with respect to either the inertial or body frame are implied in braces.



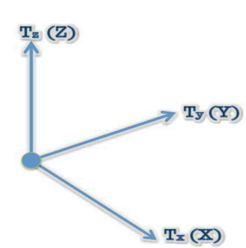


Figure 1: Body Frazme Figure 2: Inertial Frame

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IV. THRUST AND STANDARD FLIGHT OPERATIONS

Thrust is the force that is orthogonal to the propeller. It is is generated by rotor spin at a certain velocity (Eq. 1). Moreover, it accelerates the body in the direction of its force. In all the equations henceforth it' refers to t particular rotor in Fig. 3

$$|\vec{T_i}| = \rho A {v_i}^2$$

Equation 1

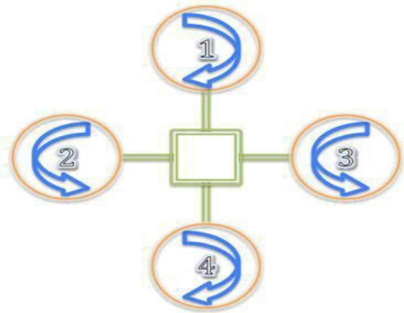

Figure 3

In eq. 1, T is determined using the parameters v (velocity), ! (air-density) and A (cross-sectional area) of the propeller. A real-time air-density reading is necessary because the density of air is correlated to external environmental factors that are not always constant. As a result, the velocity of rotors required for the quadcopter to climb up or down, or hover a fixed altitude is also variable at external conditions. So, a constant air-density reading would dramatically compromise the performance of the rotors and therefore, the overall total thrust of the quadcopter. For the latter parameter, the crosssectional areas of all the propellers are constant during anystate of the flight. However, the area of the propellers could also contribute to the amount of total thrust generated

V. TAKE-OFF, LANDING AND HOVERING

In takeoff mode all the four rotors spin in CW direction. The CW direction contributes positive net thrust {Z-axis Body frame} on the quadcopter body, thereby enabling translational motion about positive Z-axis {Inertial frame}. [2],[4],[6] In landing mode all the four rotors spin in CCW direction. The CCW direction contributes negative net thrust {Z-axis Body frame} on the quadcopter body, thereby enabling translational motion about the negative Z-axis {Inertial frame}. [2],[6] Provided all the rotors are spinning in the same direction and velocity, Eq. 2 gives the net thrust on the body.

$$net\ T = \rho A \sum_{i=1}^{4} [v_i]^2$$

Equation 2

When the net thrust of all the rotors is equal to 0, the quadcopter maintains a state of constant altitude also known as hovering. The direction of rotation of a pair of rotors at each axis is always the same. For net thrust to equal 0, the spin direction of both rotors in X-axis {Body frame} must be opposite to the spin direction of rotors in Y-axis {Body frame}. [4] (Fig. 3) The speed of all four rotors during hovering is equal direction of rotation Eq. 3 shows the net thrust from the four rotors. [9] The arrows indicate the direction of thrust in the Z-axis {Body frame}

$$net\ T = \rho A \sum_{\uparrow i=1}^{2} [v_i]^2 - \rho A \sum_{\downarrow i=3}^{4} [v_i]^2 = 0$$

Equation 3

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Furthermore, the net tangential acceleration is equal to 0 in sections 3.2 and 3.3. Therefore, translational motion is not observed in X and Y axes {inertial frame} during taking-off, landing or hovering

VI. MATHEMATICALLY DESCRIBING THE QUADCOPTER MOTION

From the law of conservation of energy we obtain Eq. 4, which is the velocity required for the quadcopter to climb from ho to any desired altitude of hf regardless of its angular orientation. Eq. 5 is the total thrust that is generated by the rotors in order to keep the quadcopter airborne at a certain desired altitude of hf given its total mass (m) and angular orientation. The magnitude of the total thrust from Eq. 6 is used to obtain the magnitude of the component vectors Tx, Ty, and Tz using Eq. 6, 7 and 8. The vector component magnitudes are with respect to the inertial frame. A specific altitude can be maintained by total thrust from the rotors such that total Tz {Inertial frame} in Eq. 8 is constant. The thrust vector of the rotor can be obtained using Eq. 9. we saw that a quadcopter must attain a certain angular orientation in order to be maneuvered. If the rotor speeds are variable, then such angular orientation is achieved where the speed of each rotor is independent. The ratio of thrust generated by the rotors is equal to the ratio. we saw that a quadcopter must attain a certain angular orientation in order to be maneuvered. If the rotor speeds are variable, then such angular orientation is achieved where the speed of each rotor is independent. The ratio of thrust generated by the rotors is equal to the ratio

$$v^2 = 4g(h_f - h_o)$$

Equation 4

$$|\vec{T}| = \frac{\rho A\, 4g(h_f - h_o) + mg}{\cos(\theta)\cos(\varphi)}$$

Equation 5

$$|T_x| = \sqrt{-|T|^2 \cos(\theta)^2 \left(1 - \frac{1}{\cos(\theta)^2}\right)}$$

Equation 6

$$|T_y| = |T| \cos(\theta) \sin(\varphi)$$

Equation 7

$$|T_z| = |T| \cos(\theta) \cos(\varphi)$$

Equation 8

$$\vec{T} = T_x\, \hat{\imath} + T_y\, \hat{\jmath} + T_z\, \hat{k}|$$

Equati on 9

A. The equations above are applicable only under the following circumstances

1) The center of mass of the quadcopter is in the center of the body [5]
2) Cross-sectional area of all the four propellers are equal
3) The adjacent arm-extensions are perpendicular to one another [5]
4) Angles and f should be less than 90o

we saw that a quadcopter must attain a certain angular orientation in order to be maneuvered. If the rotor speeds are variable, then such angular orientation is achieved where the speed of each rotor is independent. The ratio of thrust generated by the rotors is equal to the ratio that a quadcopter must attain a certain angular orientation in order to be maneuvered. If the rotor speeds are variable, then such angular orientation is achieved where the speed of each rotor is independent .We must maintain the ratio of thrust and weight by 2:1 which is must to maintain the quadcopter in air at stable height. Stability is the most important part of quadcopter.The center of mass maintain the important property which inhibit the actions taken to fly at great altitude. It can be used to provide some frequent work of traffic where a normal person takes more time to do the work . The main problem in Quadcopter is the balancing and stability system. Most of Quadcopter will be unbalance and lost stability in case there are disturbance direct on itsuch as wind.

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In this research, to solve above problem the full system of Quadcopter is design and construct. Graphical user interface (GUI) is design in this research to make control task of Quadcopter easier

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Case	Orientation	θ	φ	X	Y	Z
1	*Hovering	$\theta = 0^o$	$\varphi = 0^o$	0	0	$\pm T_z$
2	*Forward	$0^o < \theta < 90^o$	$\varphi = 0^o$	T_x	0	$\pm T_z$
	Backward	$-90^o < \theta < 0^o$	$\varphi = 0^o$	$-T_x$	0	$\pm T_z$
3	*Left	$\theta = 0^0$	$0^o < \varphi < 90^0$	0	T_y	$\pm T_z$
	Right	$\theta = 0^0$	$-90^o < \varphi < 0^o$	0	$-T_y$	$\pm T_z$
4	*Pitch + Roll	$0^o < \theta < 90^o$	$0^o < \varphi < 90^0$	T_x	T_y	$\pm T_z$
	Pitch + Roll	$-90^0 < \theta < 0^0$	$-90^o < \varphi < 0^o$	$-T_x$	$-T_y$	$\pm T$

Table 1
Shows how the different orientations of the quadcopter are related to the range of angles

VII.EVALUATION

In Eq. 5 we saw that the total thrust is subject to change depending on ! and !. Fig. 6 is the graph of angle and altitude . The graph illustrates that as the angles tends to increase the total thrust also increases. This is because more thrust {Z-axis body frame} is needed to keep the copter airborne For the purposes of further evaluation we take samples of thrust for angles 30, 45, 60 and 75 from Fig. 6. Fig. 7 is the graph of the mentioned angles vs. magnitude of Tx, Ty, and Tz. We observe that magnitude for the X and Y components increase as the angles increase. However, as expected the magnitude of the Z component of thrust is the same throughout.

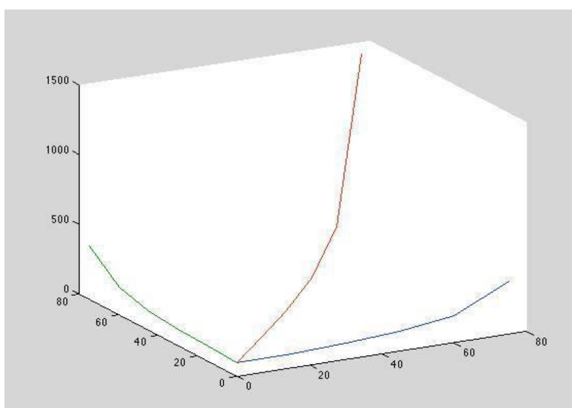

Figure 4

Brushless motors are often used in quadcopter due to their higher efficiency, reliability and lesser maintenance costs. These motors are rated in Kv (RPM/volt), also known as motor constant. Graph tells the total voltage needed for a motor to rotate at certain rpm which is equivalent to linear is the radius of propellers. It is a type of fan that transmits power by converting rotational motion into thrust. A pressure difference is produced between the forward and rear surfaces of the airfoil-shaped blade, and a fluid (such as air or water) is accelerated behind the blade.A strong propellers is the base of an quadcopter It tells the how basic u can handle it.How much wight it can load and how far it can high.Stability of whole quadcopter is basic need of it . Higher the stability the higher will be the chances stability at great altitude. Most pilots race and freestyle quadcopters smaller than 250mm down to the "Tiny Whoop" size as small as 50-60mm between the propeller shafts. Although commercially ready to fly (RTF) and almost ready to fly (ARF) are becoming more common, most racing quadcoptes are custom built by their pilots who weigh a wide variety of factors into their component selection to balance speed, agility, weight and cost. Quadcopters and other multicopters often can fly autonomously. Many modern flight controllers use software that allows the user to mark "way-points" on a map, to which the quadcopter will fly and perform tasks, such as landing or gaining altitude an open-source software/hardware combination in development since 2009, has since been adopted by both hobbyists and drone manufacturing companies alike to give their quadcopter projects flight-control

VIII. CONCLUSION

This paper presents a way to adjust thrust of the rotors via voltage supply to perform standard flight operations and to position the quadcopter into certain angular orientation depending on the circumstances of a particular flight. Depending on the circumstances of a particular flight of the copter mathematically that might be observed within a rangeset of angles. Total thrust is determined by the user defined altitude and angles Then the ratio of total thrust depending on the angle ratio is used to find the thrustfor each independent rotor that is needed to calculate thevoltage supply for the required RPM. The solution lays the foundation for further use in control scheme to develop away to autonomously control the copter for flight stabilityand precision maneuvering when following a flight path

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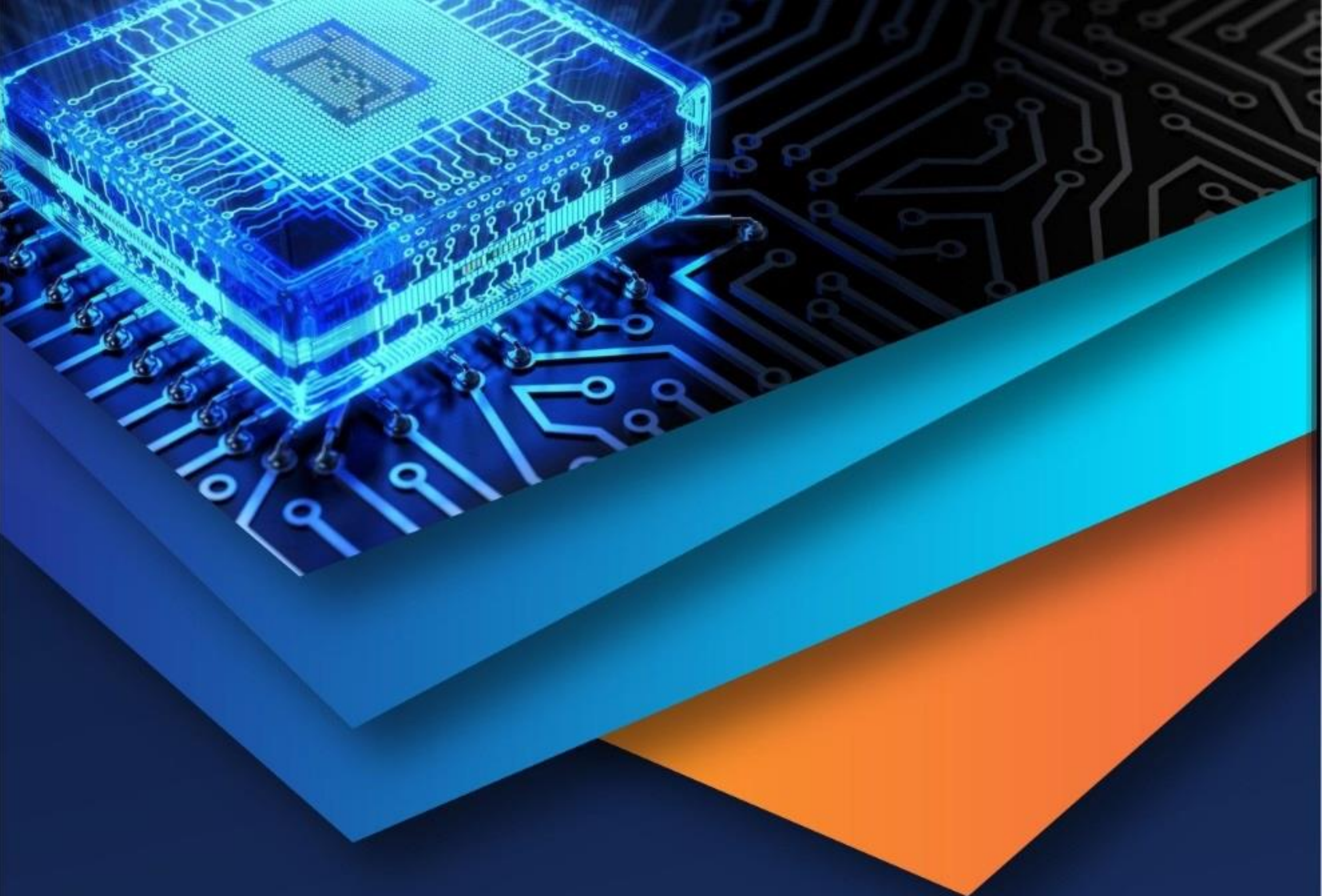

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