Quadcopter For Robotic Applications: A Review

Abhishek Jain*
School of engineering & Technology
Ansal University
Gurgaon,India
abhistud1170@gmail.com

Prof. Dr. Aynur Unal
Founder of DIGITAL MONOZUKURI
California(CA), USA
aynurunal@stanfordalumni.org

Antimdev Mishra
Assistant Professor
School of engineering & Technology
Ansal University
Gurgaon,India
antimdevmishra@ansaluniversity.edu.in

Sumit Maitra
Professor
School of engineering & Technology
Ansal University
Gurgaon,India
sumitkumarmaitra@ansaluniversity.edu.in

***Abstract* — This paper is a presentation of the design metho dology and realization of the Quad-Copter, a normal model aircraft based on a four-propeller design. The Quad- Copter can be controlled by radio transmission or operate under the guidance of limited autonomous protocols.Flight stability of the Quad-Copter is achieved using a five degrees of freedom (DoF) inertial measurement unit (IMU) . Sensor data is Integrated and processed using a proportional– integral derivative controller (PID controller), a feedback loop maintained by an on-board Atmel microcontroller.**

Keywords—UAV;Navigation; mapping; microcontroller; ANN; AI Sensor;Genetic Algorithm.

I. INTRODUCTION

A quadcopter, also called a quadrotor helicopter, quadrocopter, quadrotor, is a multicopter that is lifted and propelled by four rotors. Quadcopters are classified as rotorcraft, as opposed to fixed-wing aircraft, because their lift is generated by a set of revolving narrow-chord airfoils. Unlike most helicopters, quadcopters generally use symmetrically pitched blades; these can be adjusted as a group, a property known as 'collective', but not individually based upon the blade's position in the rotor disc, which is called 'cyclic' (helicopter). Control of vehicle motion is achieved by altering the pitch and/or rotation rate of one or more rotor discs, thereby changing its torque load and thrust/lift characteristics. Nowadays, the quadcopters can perform quick and complex maneuvers, navigate autonomously in structured and unstructured environments and cooperate in manipulation and transportation tasks . However, the commercial quadrotor helicopters are too expensive to be used by students or small research teams. Although there exist several quadcopter toys, these are too small to carry necessary sensor equipment. In recent years, several community projects aimed to develop an affordable quadrotor helicopter have appeared . However, these projects are still in progress and have not filled the gap between expensive commercial platforms and sensorless toys.

II. PECULIARITY

More recently quadcopter designs have become popular in unmanned aerial vehicle (UAV) research. These vehicles use an electronic control system and electronic sensors to stabilize the aircraft. With their small size and agile maneuverability, these quadcopters can be flown indoors as well as outdoors.

III. QUADCOPTER DYNAMICS

We will start deriving quadcopter dynamics by introducing the two frames in which will operate. The inertial frame is defined by the ground, with gravity pointing in the negative z direction. The body frame is defined by the orientation of the quadcopter, with the rotor axes pointing in the positive z direction and the arms pointing in the x and y directions. Quadcopter Body Frame and Inertial Frame.

IV. CONTROL TECHNIQUE

Each rotor produces both a thrust and torque about its canter of rotation, as well as a drag force opposite to the vehicle's direction of flight as shown in fig.1. If all rotors are spinning at the same angular velocity, with rotors one and three rotating clockwise and rotors two and four counter clockwise, the net aerodynamic torque, and hence the angular acceleration about the yaw axis is exactly zero, which implies that the yaw stabilizing rotor of conventional helicopters is not needed. Yaw is induced by mismatching the balance in aerodynamic torques (i.e., by offsetting the cumulative thrust commands between the counter-rotating blade pairs).

Angular accelerations about the pitch and roll axes can be caused separately without affecting the yaw axis. Each pair of blades rotating in the same direction controls one axis, either roll or pitch, and increasing thrust for one rotor while decreasing thrust for the other will maintain the torque balance needed for yaw stability and induce a net torque about the roll or pitch axes. This way, fixed rotor blades can be made to manoeuvre the quad rotor vehicle in all dimensions. Translational acceleration is achieved by maintaining a non-zero pitch or roll angle.Four rotors are used, rather than three, six or some other number, because four offers two convenient axes of symmetry. With four rotors it is easy to imbalance side-to-side thrust, thus giving a roll movement. As this pair of side rotors rotate in the same direction and one is increased whilst the other is decreased, the overall torque reaction and yawing force remains zero. A similar geometry applies to controlling pitch, using the fore-and-aft rotor pair. In piloting a conventional helicopter, controlling yaw by balancing out the torque reaction from the main rotor is a difficult process and requires considerable practice.

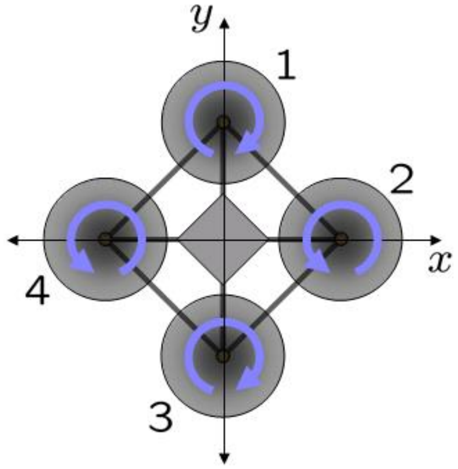

Fig. 1 Schematic of reaction torques on each motor of a quadcopter aircraft, due to spinning rotors. Rotors 1 and 3 spin in one direction, whilerotors 2 and 4 spin in the opposite direction, yielding opposing torques for control.

V. SENSOR SUBSYSTEMS

The Quad-Copter requires several sensors to perform tasks that range from cri tical, such as flight stability, to optional, such as the high altitude sensor. Additionally,sensors are an important part of the Quad-Copter's autonomous functions such as altitude maintenance, path finding, and object avoidance. The different sensor subsystems can be organized into the following categories: flight stability sensors, proximity sensors, yaw or direction sensor, and the navigation sensor (GPS).

A. Flight Stability Sensors

The flight stability sensors are a critical system for the Quad-Copter to remain in flight. The system consists of a triple axis accelerometer and a dual axis gyroscope combined into a 5 DoF IMU. The accelerometer is the ADXL335 from Analog Devises, and the gyroscope is the IDG500 from InvenSense. The outputs from the sensors are combined using a sensor fusion algorithm, which outputs an improved estimate of the angular state. The output of the senor fusion algorithm is the input to the linear control system which adjusts the speed of each motor to maintain a level hover. The sensor fusion algorithm used is based on the Kalman filter but with an adaption that uses the gyroscope to monitor and correct for angular velocity about the Quad-Copter's axes.

B. Proximity Sensors

Proximity sensors will be used for two distinct purpose on the Quad-Copter: a downward oriented sensor to detect the distance to the ground, and a forward oriented sensor to detect obstacles such as trees and walls. Both sensor will be ultrasonic range finders, specifically, the MaxSonar LV-EZ2s from MaxBotix. Both sensors are necessary for any sort of autonomous flight protocols such as object avoidance or automatic altitude control. The LVEZ2 have a maximum range of about 20 ft. for a large object such as a wall, however; this range diminishes significantly when detecting smaller targets. Both of the LV-EZ2 ultrasonic sensors will be remote from the main PCB and connected with 6-12 of wire to header pins.

C. Yaw/Direction Sensor

Yaw is the movement about the vertical axis of the Quad-Copter. Yaw must be stabilized as a requirement for attaining a stable hover. Yaw can be manipulated by increasing the speed of two motors along a single axis while simultaneously decreasing the speed of the motors on the other axis. This will rotate the Quad-Copter in place while maintaining a net equilibrium on the vertical axis. This change to the yaw can be initiated either directly by the user giving a wireless command or autonomously by the microcontroller using sensor data from a digital compass. The digital compass used for this purpose is the HMC6352 two-axis magnetometer from Honeywell, which communicates with the microcontroller via a two-wire serial interface. The compass heading can be used as a component input of the stabilization loop to maintain a stable heading. Furthermore, the compass can be used in conjunction with the GPS module to autonomously plot movement to a GPS coordinate.

D. Navigation/Position Sensor (GPS)

A GPS module will be integrated into the design of the Quad-Copter which will be a central component of the autonomous mode of operation. The GPS system will allow the Quad-Copter to hover in place by repeatedly returning to a point of origin, or to move towards a given coordinate. The MediaTek MT3329 GPS module will be used. The MT3329 has an antenna integrated into the casing of the chip which is an optimal design for the Quad-Copter. It has a positional accuracy of within 3 meters and a sensitivity of up to -165 dBm. The MT3329 also has coding and firmware support available from the DIYdrones website. Originally, the plan was to mount the chip directly onto the main PCB, subsequently; the design has changed to the GPS module being mounted on a frame.

VI. AUTONOMOUS FLIGHT

Quadcopters and other multi-copters often can fly autonomously. Many modern flight controllers use software that allows the user to mark "**waypoints"** on a map , to which the quadcopter will fly and perform tasks, such as landing or gaining latitude.

VII. STABILITY

It is believed that stability is the foremost challenge for any effort to build a model sized robotic rotorcraft. In the absence of natural damping, all rotorcrafts must be constantly stabilized by the pilot or auto-pilot. In model sized helicopters this presents a formidable difficulty, because of the much smaller time-constants. This is the reason why model-helicopter pilots need months and months of training, just to keep their helicopters in stable hovering. Hence extra-speciality features are needed to be embed for achieving stability.

VIII. OPEN SOURCE CODE/SOFTWARE

The open source code for this quadcopter is based on AVRstudio architecture. The AVRstudio is a C/C++ based software for making relevant codes for robotic projects. This quadcopter can be built on an ARDUINO APM board or a ATMEGA 168P microcontroller as shown in fig. 2. These hardware boards include all the basic components needed for making a quadcopter. The most important part for implementing the project is the interfacing of these hardwares with the AVRstudio software. The solution to this problem is that the hardware should be provided with the program-burner synchronized with AVRstudio software for burning the codes on the IC.

Fig.2 Arduino APM Microcontroller

IX. PRINCIPLES OF WORKING

In order to properly model the dynamics of the system, we need an understanding of the physical properties that govern it. We will begin with a description of the motors being used for our quadcopter, and then use energy considerations to derive the forces and thrusts that these motors produce on the entire quadcopter. All motors on the quadcopter are identical, so we can analyze a single one without loss of generality. Note that adjacent propellers, however, are oriented opposite each other; if a propeller is spinning "clockwise", then the two adjacent ones will be spinning "counter-clockwise", so that torques are balanced if all propellers are spinning at the same rate.

A. Motors

Brushless motors are used for all quadcopter applications. For our electric motors, the torque produced is given by

$$t = Kt(I - Io)$$

where t is the motor torque, I is the input current, I0 is the current when there is no load on the motor, and Kt is the torque proportionality constant. The voltage across the motor is the sum of the back-EMF and some resistive loss:

$$V = IRm + Kv$$

where V is the voltage drop across the motor, Rm is the motor resistance, w is the angular velocity of the motor, and Kv is a proportionality constant (indicating back-EMF generated per RPM). We can use this description of our motor to calculate the power it consumes. The
power is

$$P = IV = \frac{(t + Kt \times Io)(Kt \times IoRm + tRm + KtKv)}{Kt2}$$

For the purposes of our simple model, we will assume a negligible motor resistance. Then, the power becomes proportional to the angular velocity:

$$P = \frac{Kv(t + Kt \times Io)}{Kt}$$

Further simplifying our model, we assume that Kt I0 _ t. This is not altogether unreasonable, since I0 is the current when there is no load, and is thus rather small. In practice, this approximation holds well enough. Thus, we obtain our final, simplified equation for power:

$$P = \frac{Kv \times tw}{Kt}$$

B. Forces

The power is used to keep the quadcopter aloft. By conservation of energy, we know that the energy the motor expends in a given time period is equal to the force generated on the propeller times the distance that the air it displaces moves (P .d t = F .d x). Equivalently, the power is equal to the thrust times the air velocity

$$(P = F\, dx/dt).$$

$$P = T \times Vh$$

We assume vehicle speeds are low, so vh is the air velocity when hovering. We also assume that the free stream velocity, Vh, is zero (the air in the surrounding environment is stationary relative to the quadcopter). Momentum theory gives us the equation for hover velocity as a function of thrust,

$$Vh = (T/pA)^{1/2}$$

where r is the density of the surrounding air and A is the area swept out by the rotor. Using Note that in the general case, t =~r _~F; in this case, the torque is proportional to the thrust T by some constant ratio Kt determined by the blade configuration and parameters. Solving for the thrust magnitude T, we obtain that thrust is proportional to the square of angular velocity.

X. POWER

Power has been divided into two separate parts: the motors and the main components for operation and control. This was found as the best solution to minimize noise and to protect the main board from unforeseen problems based on inexperience with PCB design. Since the majority of the required power needed to be drawn is consume by the motors, the best solution is to directly
connect the lithium polymer (LiPo) batteries to the motors. Since the biggest concerns regarding the LiPo batteries are mass and cost, the best route to minimize both of these issues was to select either one very large battery or two smaller ones. This design will implement the latter. The Esprit EM-35 3-cell 35C 2250mAH are an excellent source in terms of mass, balance, and charge capacitance. The batteries will be directly connected to the ESC, which are rated at 30A per ESC. From preliminary testing, a 5 minute window at the maximum setting is allowed, which reinforces the minimum flight time. The main power source for the main board and the remaining peripheral components will be powered using alkaline batteries; a 9V battery for the video system, and a 9Vm battery for the main board and the remaining external components. The lowest power to be regulated on the board is implemented at 2.98V by an LM317-ADJ. This will be the main power to the gyroscope, since the component's maximum voltage tolerance is 3.3V. Using this level of voltage will safely guarantee the use of component. Figure 3 depicts the schematic implemented.

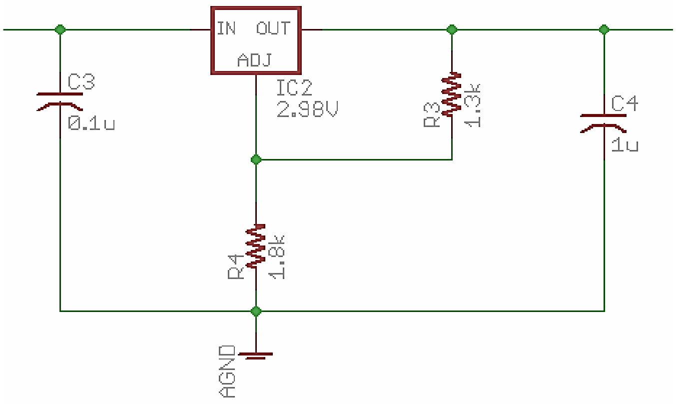

Fig. 3 LM317-ADJ setup for 2.98 V

XI. CONTROL STRATEGY

The control strategy for the flying/hovering modes involved the development of two loops. The outer loop is responsible for providing a desired roll and pitch (and the velocities) to the inner control loop in an effort to achieve desired *X* and *Y* coordinates (or velocities). The (faster) inner loop is responsible for achieving the desired roll and pitch.

For hovering, the outer loop controls designed to drive the system towards a desired Cartesian position are

$$\varphi_d = \arcsin(K1(Yd - Y0) - K2\,\dot{Y}0)$$

$$\theta_d = -\arcsin[(K1(Xd - X0) - K2\,\dot{X}0)/\cos\varphi]$$

where$K1$ and$K2$ are simple control gains. The use of adaptiveneural techniques the for inner loop allows the controller to handle model uncertainty as well as possible disturbances. The four nonlinear equations depend on variables in vector **q** and it is assumed the CMACs uniformly approximate nonlinear terms:

$$\mathbf{f}(t, \mathbf{q}) = \hat{\mathbf{f}}(\mathbf{q},\mathbf{w}) + \epsilon(t, \mathbf{q}) = \mathbf{T}\mathbf{w} + \epsilon(t, \mathbf{q})$$

where **T** is now an $n \times m$ matrix of activated basis functions and

$$\epsilon(t, \mathbf{q}) = \mathbf{d}(t) + \mathbf{d}_{approx}(\mathbf{q})$$

represents all time-varying disturbances and the approximation error.

XII. ARTIFICIAL INTELLIGENCE

A broad definition of Artificial Intelligence (AI) can be the automation of activities that are associated with human thinking, such as decision making, problem solving, learning, perception and reasoning .

The AI tools of interest to the robotics community include fuzzy logic (FL), adaptive fuzzy logic (AFL), expert system(ESs), artificial neural networks(ANNs) and genetic algorithms(GA's).

A. FL and AFL Applications

FL and AFL are very powerful AI techniques allocating capacitor banks while maintaining harmonic distortion levels within acceptable limits

- Estimating movements indices using fuzzy constraints.
- Automating the identification of abnormal system operation using adaptive fuzzy techniques.
- Predicting system abnormal operation
- Automating system and better response.
- Estimating the dynamics of a quadrotor system.\
- Analysing the behavior of quadcopter on varying the controls.

B. Neural Network Application

In Artificial neural network two common types of learning that are often mentioned are supervised learning and unsupervised learning .One often understands that in supervised learning, the system is given the desired output, and it is required to produce the correct output for the given input, while in unsupervised learning the system is given only the input and the objective is to find the natural structure inherent in the input data. We, however, suggest that even with unsupervised learning, the information inside the input, the structure of the input, and the sequence that the input is given to the system actually make the learning "supervised" in some way

ANNs have extensive use in power quality, main applications are:

- Identifying control events from quadcopter.
- Modeling the patterns of quadcopter
- Identifying high response.
- Achieving the calibration among the motors of the quadrotor system.
- Generating the stabilization theory of the quadcopter.

C. Genetic Algorithm

GA's are considered to be an excellent intelligent paradigm for optimization using a multi-point, probabilistic, random, guided search mechanism. Some applications are documented as:

- Developing a fault processing system and diagnose system for robotics using AI tools.
- Using Fault tree induction Algorithm for classification of copters.
- Integrating AI and advanced communication technologies in substation intelligent electronic devices (IED).

Latest research is going on assessing the robotics events by Empirical mode decomposition (EMD) introduced by Huang together with Hilbert transform for extracting instantaneous amplitude and frequency from multi component non stationary signals.The probabilistic neural network (PNN) is a supervised neural network that is widely used in the area of pattern recognition. The following features are distinct from other networks in learning process.

- It is implemented using probabilistic model, such as Bayesian Classifiers
- No Learning Processes are required.
- No need to set the initial weights of the network.

XIII. APPLICATIONS

A. Agricultural Applications

Traditionally, crop monitoring and spatial data acquisition are costly and laborious. By other hand, drones can be placed in the context of real time monitoring and disease control. Drones can quickly travel through strawberry fields, capturing and transmitting images. The technology already showed satisfactory results in other crops such as wheat, soybeans and corn, increasing the value and the quality of products, decreasing costs, expanding the productivity and improving the proper use of agricultural supplies. In the case of strawberry, this scenario can be obtained through controlled, accurate and efficient application of pesticides using drones adapted to this task.

However, plant diseases warning systems have not yet met the expectations for appropriate disease management. Among the problems are the excessive complexity or simplicity of the models, the lack of portable solutions, implementation costs, weather stations maintenance and user risk aversion.
The overview is as under:

- At an average of $2 per acre for a walking visual inspection or an aerial survey to take an image of crop fields, the return on investment on the purchase of an aerial camera drone can be met quickly for famers

- Drones can reduce farmers operating costs and improve their crop yields by giving farmers timely information they need for quick management intervention.

- Drones can be useful in supervising the quality of crops on the field from time to time and can ensure the proper utilization and savage of resources.

B. Rescue Operations

Another important application of a drone includes the use in search and rescue operations. In the recent times the development in technologies have made it a much easier task when it comes to rescue operations. A lot of modern technologies have been employed for these operations in the recent past including the Google views and GPS tracking.
But the most advanced and reliable in the recent times is the use of drones in search operations. Many rescue operations in the recent floods in Arizona and the other natural calamities in the US and round the world have been successfully carried out.
Quadcopter gives a helping hand by giving clear aerial images of the affected places, by which real-time situations can be observed even at the remote locations.
The major aspects of drones in rescue operations are:

- Real-time video streaming of the affected places and perfect aerial images.
- Efficient and reliable operation, thus eliminating the role of manpower.

C. Industrial Applications

Over the couple of years, the drones have found an immense application in different industries. Due to its high payload capacity, the drones can be used for the delivery of packages to remote locations by the use of GPS tracking.
While drones are unlikely to become a part of our daily lives in the immediate future, they will soon begin taking on much higher roles for business and some individual consumers, from delivering groceries to revolutionizing private security, to change the way farmers manage their crops-perhaps even aerial advertising.
Here are some points that will impact how drone industry develops:

- American regulators plan to phase in commercial drone flights beginning in 2015, starting with limited flights of small drones weighing 55 pounds or less.
- Retail & e-commerce- along with the related logistics and shipping industries.
- Currently, military applications dominate the global UAV market, but commercial applications will quickly ramp up over the next ten years.
- Some component industries related to drones such as GPS & sensors manufacturers have accelerated in the recent past.
- Shipping industries are keeping a futuristic eye on the development of the aerial industry, which is certainly going to be an x-factor for the shipping industry.

XIV. CONCLUSION

In this paper we have derived equations of motion for a quadcopter, starting with the voltage-torque relation for the brushless motors and working through the quadcopter kinematics and dynamics. We ignored aerodynamical effects such as blade-flapping and non-zero free stream velocity, but included air friction as a linear drag force in all directions.
From this paper we have arrived on the conclusion that the quadcopter can proven out to be helpful in the following areas, such as:

- Beneficial in agriculturural applications.
- Used as GPS Tracker.
- Used for monitoring purposes.
- Helpful in architectural mapping.
- Convenient for R&D purpose.
- Used in military applications.
- Used for spying.
- Capable of lifting light loads

REFERENCES:

[1] N. Michael, D. Mellinger, Q. Lindsey, and V. Kumar. The GRASP Multiple Micro-UAV Testbed. Robotics Automation Magazine, IEEE, 17(3):56–65, Sept. 2010.

[2] S. Bouabdallah and R. Siegwart. Full control of a quadrotor. In Intelligent Robots and Systems, 2007. IROS 2007. IEEE/RSJ International Conference on, pages 153–138, 9 2007-nov. 2 2007.

[3] Ünal, A., “Snow Cap” Patent for electronics manufacturing e-markets, E2open, Feb. 2001.

[4] Ünal, A., “Generalized e-hubs: A Stack of Pancakes” Patent for electronics manufacturing e-markets, E2open, January 2001.

[5] Ünal, A., “Integrating Different Processes of Electronics Manufacturing as Generalized e-hubs: Revolving Doors” Patent for electronics manufacturing e-markets, E2open, January 2001.

[6] S. Lupashin, A. Sch¨o andllig, M. Sherback, and R. D’Andrea. A simple learning strategy for high-speed quadrocopter multi-flips. In Robotics and Automation (ICRA), 2010 IEEE International Conference on, pagesn1642 –1648, May 2010.

[7] N. Michael, D. Mellinger, Q. Lindsey, and V. Kumar. The GRASP Multiple Micro-UAV Testbed. Robotics Automation Magazine, IEEE, 17(3):56–65, Sept. 2010.

[8] A. Censi. An ICP variant using a point-to-line metric. In Robotics and Automation, 2008. ICRA 2008. IEEE International Conference on, pages19–25,may2008.