Intelligent Flying Robots - Quadcopters

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Abstract **:** ***Robots that can fly, that have four arms with motors buzzing while they rotate, fixed on them are camera gimbals that capture everything and multiple sensors that regulate flow of information, these are Quadcopters. Classified under rotorcrafts, quadcopters are unmanned radio controlled aircrafts popular among hobbyists and companies for their novel applications. This paper examines the features of a quadcopter, their applications, limitations and future scope.***

Keywords: autonomous robot, 360° sensing, obstacle avoidance, MSI

1. Introduction

Multicopters are unmanned aircrafts that have a central hub with electronics, power and sensors onto which are mounted arms that hold motors and propellers to provide lift and are guided by remote control or on-board computers. The number of arms gives the name : a tricopter (three arms), quadcopter (four arms), hexacopter (six arms) and an octocopter (eight arms).

2. History

The very first experimental attempts of flying rotorcrafts were carried out by Jacques and Louis Breguet along with Professor Charles Richet who designed a four rotor aircraft which was known as the Breguet – Richet Gyroplane. This quadrotor did take off but was very unstable and achieved flight only upto a few feet above ground. In the 1920's, Etienne Oehmichen experimented with his rotorcraft which had four rotors and eight propellers and achieved flight for about seven minutes, this was the earliest successful attempt at quadcopter designing and flying.

3. Fundamental Components

3.1 Airframe – Airframe is the mechanical structure of the rotorcraft minus the propulsion and technical systems. All other components – motors, propellers, batteries, computer etc. are mounted to the airframe. The most popular choices for modern quadcopter frames are carbon fibre, fiberglass, aluminium etc. These frames have a centre plate which has mounting spaces for electronics and batteries as well as arms which have motor mounting pads. [5] Different types of popular frame configurations are depicted in Figure 1.

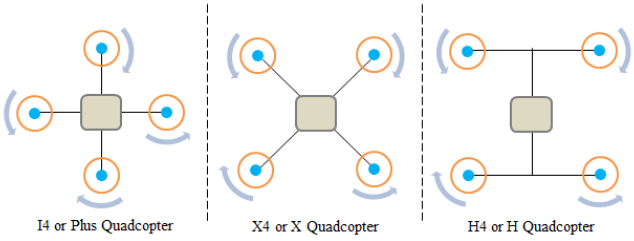

Figure 1: Popular Quadcopter Frame Configurations

3.2 Electronic Speed Controllers – An electronic speed controller or ESC is an electronic circuit with the purpose to vary an electric motor's speed, its direction and possibly also to act as a dynamic brake. An ESC stands between the low current required to operate microelectronic flight control systems and the raw power required to turn propellers. It reads the speed the motor is turning at, takes inputs from the flight controller and applies the power to keep the motor turning at desired speed. [3,5] The wiring diagram of an speed controller – motor connection is illustrated in Figure 2

Figure 2: ESC – Motor Wiring Diagram

3.3 Brushless Motors– The motors of your drone is what your propellers are connected to which causes them to spin around and generate thrust to enable the

drone to fly. In case of multirotors, the motors generate upward thrust which keeps the quadcopter flying. A brushless motor consists of two main sections a) Rotor – the part that rotates and has magnets mounted in a radial pattern. b) Stator – the part that doesn't rotate and has electromagnets. A general rule is that you should at least be able to provide twice as much thrust than the weight of the quad; this is the bare minimum to ensure stable hovering of the quadcopter. In general, brushless motors are specified in kV rating which is, the theoretical increase of motor RPM when the voltage increases by one volt without load or on no load. [3,5]

Motor Specifications :

a. kV Rating (RPM/V)
b. Weight (g)
c. Maximum Current (A)
d. Maximum Voltage (V)
e. Length, Shaft length, Diameter (mm)

3.4 Propellers–Rotorcraft propellers come in a variety of diameters and pitches as well as materials such as plastic, carbon fibre etc. The flight efficiency of a quadcopter is closely related to the amount of air contacting the surface of the propeller and the column of air it creates around it due to its motion. For a quadrotor, four propellers are essential out of which two turn clockwise and two anticlockwise which generate the required amount of thrust needed to lift the quadcopter. [3,5]

3.5 Battery – A battery pack powers the motors and provides them with the energy to generate thrust to lift the quad up. The most popular type of battery composition currently is Lithium – Polymer (Li - Po). A Li – Po battery pack consists of one or more cells each producing a nominal 3.7 volts of power. The amount of power contained in the battery is measured in milli ampere hour (mAh) ratings. Advantages of Li – Po batteries are that they are lightweight, compact and have about four times the energy density ofNiCad/NiMH batteries which makes them ideal for rotorcraft operations. [3,5]

Battery Specifications :

a. Capacity (mAh)
b. Cell count (S or P)
c. Voltage (V)
d. Discharge Rating (C)

3.6 Brain/Flight Controllers–The most important unit of the quadcopter is its on-board brain circuit that controls all the electronic modules and supplementary sensors. Prebuilt and pre-programmedversions of the on-board circuits are known as flight controllers which are singular units that consist of automated speed variation systems, IMU units and other sensors as per the requirement of the quadcopter. Recently, various microcontrollers along with their supported modules and sensors are being used as on-board brains. Importantly, the type of flying – Freestyle, Aerial Photography, Autonomous Missions, or utilization of the quadcopter determines the type of flight controllers. [3,5]

Examples of industry standard flight controllers :

a. NAZE32 : Modern 32 bit processor unit running at 3.3 V/72 MHz Upto eight channels RC input. Built in telemetry inverter.
b. KK2 : An Atmel Mega 644PA 8 – bit AVR based microcontroller with 64k of memory. GUI based options for calibration of ESC's, radio, propellers and selection of craft type.
c. DJI Naza-M Lite : Has Advanced Altitude Stabilization Algorithm with Multiple Flight Control mode and built in Gimbal Stabilization Function.

3.7 Transmitter and Receiver –The control system of a quadcopter comprises of a transmitter and receiver. The transmitter (TX) is the radio control system that transmits commands to the receiver (RX). On the other end of the system is the receiver with a characteristic frequency required for broad range communication and control. All transmitter systems offer different number of channels which are unique remote-controllable actions. The minimum number of channels required to pilot a quadrotor or any other multicopter is four : throttle, roll, yaw and pitch. Receiver frequencies are generally in gigahertz magnitude which is sufficient for quadcopter flight domain. The transmitter and receiver modules are highly customizable with respect to their features (number of channels, frequency, modes etc.) [6]

3.8 Miscellaneous–Quadcopters are not just aboutthe motors or the flight controllers they have on them, they are highly customizable starting with the frame till the different modules on it. These multirotors could be equipped with lights, camera modules, gas and barometric sensors, facial recognition modules, GPS or Wi-Fi connectivity hubs, thermal imagers, display modulesetc. to make them more productive.

4. Flight Dynamics

Though being rotorcrafts that achieve vertical take-off and landing (VTOL), even quadcopters are subjected to all disciplines of aerodynamics that have an effect on ordinary aircrafts. These aerodynamic principles are often neglected by a quadcopter's frame design which is generally based on providing strength while being lightweight and compact. Thus, when designing a frame, basic aerodynamic principles like thrust and torque generation, drag force, disturbances due to wind gusts, location of centre of gravity, susceptibility to vortex ring state etc. must be taken into consideration. Like other aircrafts, quadcopters too have similar motion terminologies, that is, the different types of movements it shows with respect to different axes in its inertial frame of reference.[7]

Motion Terminologies :

a. Hover, Uplift and Downfall : Variation in speed of all the four motors with a uniform gain/loss helps the quadcopter to ascend/descend. When on ground, the throttle (transmitter command) is set to maximum for initial uplift and then maintained at a constant rate for hovering and altitude control.[7]

b. Pitch : The movement of a quadcopter in the forward or backward direction is known as pitch motion. The pitch axis is the lateral or transverse axis. Forward pitch is achieved by varying the speed of the front two motors (designated as per frame design)which tilts and makes the quadcopter move in forward direction. Movement in reverse (backward) direction is achieved by varying the speeds of the rear motors and maintaining the speed of the fore ones.[6]

c. Roll : Sideward movement of the quadrotor, either to the left or right is the roll motion. This is achieved by the variation in speeds of motors on the same side (left or right)while maintaining the speeds of motors on the opposite side. The roll axis is along the longitudinal axis.[6]

d. Yaw : It is the deviation or rotation of the head of quadcopter either to left or right. Two motors spin in clockwise direction and the other two in the opposite direction. Thus, changing the speed of any one while counter-balancing the others makes the quadcopter to yaw.[6]

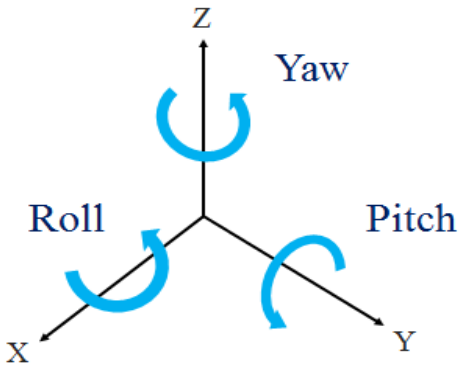

Figure 3: Motion Terminologies of a Quadcopter

5. Applications

Aerial/Action Photography : One of the mainstream uses of quadcopters and other multirotors is aerial photography. Quadcopters with camera gimbals are extensively used for filming and video making. The camera modules interconnected with the on-board computer are placed either above or below the base plate for uninterrupted viewing. Also with the help of these types of quadcopters the creation of "virtualwalkthroughs" is possible. Cameras with 4k recording, image optimization and stabilization and facial recognition with real time interfacing provide the best results for filming purposes.[4]

Agriculture : Quadcopters with miniature sprinklers or sprayers fixed on long shafts can be used to irrigate farms uniformly. A quadcopter is first fed with a mapped area and flight plan of the farm patch along with GPS coordinates and then the irrigation/spraying operation is carried out. These specialized quadcopters are lightweight, compact and have shaft arrangements on the base plate or on their booms. Advantages of this method include spraying uniformity, precision and it can possibly replace human operations of irrigation and fertilizer/pesticide/insecticide spraying.[1,4]

Surveillance, Survey and Security : Using a methodical flight pattern, routine and specific surveillance spots quadcopters can provide real-time road traffic information, monitor the streets of a sector, investigate archaeological sites etc. Such quadcopters are of inverted propeller type and have cameras mounted on servos for 360° rotation for unobstructed viewing. A quadcopter of this set is also useful for monitoring activities in animal sanctuaries to ward off poaching activities and mine surveying.[1,4]

Disaster Management: Medium sized quadcopters can be effective in search and rescue operations during calamities. Quadcopters are highly maneuverable and can fly easily into difficult access areas. For example, in a tsunami struck area,

quadcopters with high definition cameras and thermal imaging can easily locate people and pass real-time image feeds to the disaster relief services. Surveillance quads can easily spot wildfires or landslides and can prove to be instant sources of information needed for effective disaster management.

Aircraft Inspections : Today, airplane inspections are done by trained engineers on the ground where inspecting the underside of the aircraft is easy, but the sides and tops prove difficult and require platforms that can be moved which is time consuming. Quadcopters can fly all around the plane within a finite perimeter, taking snapshots and videos instead of a physical inspection. This has a number of benefits :

a. Quadcopters can view all aspects of the aircraft flying in a specific perimeter around the plane which eliminates the need of special platforms
b. They can get clear snapshots of all the aircraft areas which helps in easy detection of flaws
c. Engineers can control quads in a centralized area with real time reviewing of the aircraft.

5.1 Product Deliveries : A drone delivery system is designed to deliver packages to customers in 30 minutes or less considering the average flight time a battery pack provides. It majorly depends upon two factors :

a. Route Density : Number of drop-off locations on the flight course
b. Drop Size : Number of parcels per stop on the flight route

Presently, quadcopters can only make a single package drop-off within a time frame and have to fly back to the base for recharging. Quadcopters can deliver all kinds of packages that are compatible with their thrust-weight ratio and also have been used to deliver food products and medicines.

Swarm Flying :Quadcopters can be programmed and linked to each other to fly together in swarms or different formations. Swarm flying (Flying in formations) method is advantageous and can be an interesting application. Nano quadcopters in a formation can be used as pick and place tools that fly over to pick an object and then place it at a specified location. It is time saving and different objects can be picked up by simultaneously by different quadrotors. Also, quadcopters equipped with gas sensors can hover in a large, widely spaced formation to sense the changes in the atmosphere and even detect smog and smoke.

6. Limitations

Quadcopters prominently depend upon battery technology as batteries power the motors. Presently, a Li-Po battery provides about an average 30 – 35 minutes of flight time on a single charge. These batteries are also prone to thermal damage and can get puffed up if a nominal charge is not maintained.[5]

It requires skill and experience to properly control and maneuver a quadcopter which otherwise could lead to damage of surrounding property and damage to the quad itself. Proper functioning of the quadrotor can be ensured by the proper calibration of ESC's, IMU units and the flight controller. Flight controllers can sometimes malfunction due to distortion or mechanical vibrations produced by the rotating motors causingthe quadrotor to fly haphazardly. Whereas accessing and properly calibrating ESC's, gyroscopes, accelerometers and other IMU units results to an increased complexity in the flight stability algorithm.[1,2]

The construction complexity and expenditure increases with the increase in the different modules or units mounted on the quadcopter which sometimes is commercially non-viable.

7. Future Quadcopters

Quadcopters of the future will be compact and might have foldable arms for increased storage space. Their design complexity will be reduced by the technological advancements in 3D printing and battery technology. They would no longer be controlled by joysticks and would be made completely autonomous. Quadrotors would be made environment friendly so that they could be easily disposed off if trashed or damaged. Forthcoming, there will be development of micro quadcopters that can fly together in swarms for sanitization, disease prevention and fumigation operations. Microsoft has already begun experiments with quadcopters equipped with bug collection devices to catch mosquitoes and other bugs to help prevent vector-borne diseases.

Researchers at e-Volo, a German engineering firm have developed prototypes of a multirotor named Volocopter that has 18 rotors and can carry four to six people. This muticopter will be manned, simple to fly and will be emission free. Trials and testing have begun on this multirotor which evidently states the possibility of quadrotor flying services in the future that could transport people. Also, the evolution of pet quads that are mapped to an individual that can follow them anywhere and carry their belongings from one place to another might be another future possibility.

8. Conclusion

With their increasing presence, quadcopters are being termed as the next great tech in the world. Numerous applications, design simplicity and complete customization are some aspects which make quads favourites among hobbyists, technology enthusiasts and even for commercialization. There exist some limitations that hinder the full potential of quadrotors but they will shortly be side-lined by the advancements in technology.

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