A quadcopter, also called a quadrotor helicopter, quadrocopter, quadrotor and quadracopter, 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' (see 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.

Early in the history of flight, quadcopter (referred to as 'quadrotor') configurations were seen as possible solutions to some of the persistent problems in vertical flight; torque-induced control issues (as well as efficiency issues originating from the tail rotor, which generates no useful lift) can be eliminated by counter-rotation and the relatively short blades are much easier to construct. A number of manned designs appeared in the 1920s and 1930s. These vehicles were among the first successful heavier-than-air vertical take off and landing (VTOL) vehicles. However, early prototypes suffered from poor performance, and latter prototypes required too much pilot work load, due to poor stability augmentation and limited control authority.

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.

There are several advantages to quadcopters over comparably-scaled helicopters. First, quadcopters do not require mechanical linkages to vary the rotor blade pitch angle as they spin. This simplifies the design and maintenance of the vehicle. Second, the use of four rotors allows each individual rotor to have a smaller diameter than the equivalent helicopter rotor, allowing them to possess less kinetic energy during flight. This reduces the damage caused should the rotors hit anything. For small-scale UAVs, this makes the vehicles safer for close interaction. Some small-scale quadcopters have frames that enclose the rotors, permitting flights through more challenging environments, with lower risk of damaging the vehicle or its surroundings.

Due to their ease of both construction and control, quadcopter aircraft are frequently used as amateur model aircraft projects.
History

Early attempts

Oehmichen No.2 (1920)
Etienne Oehmichen experimented with rotorcraft designs in the 1920s. Among the six designs he tried, his helicopter No.2 had four rotors and eight propellers, all driven by a single engine. The Oehmichen No.2 used a steel-tube frame, with two-bladed rotors at the ends of the four arms. The angle of these blades could be varied by warping. Five of the propellers, spinning in the horizontal plane, stabilized the machine laterally. Another propeller was mounted at the nose for steering. The remaining pair of propellers were for forward propulsion. The aircraft exhibited a considerable degree of stability and controllability for its time, and made more than a thousand test flights during the middle 1920s. By 1923 it was able to remain airborne for several minutes at a time, and on April 14, 1924 it established the first-ever FAI distance record for helicopters of 360 m (390 yd). It demonstrated the ability to complete a circular course and later, it completed the first 1 kilometre (0.62 mi) closed-circuit flight by a rotorcraft.\[1\]

de Bothezat helicopter (1922)
Dr. George de Bothezat and Ivan Jerome developed this aircraft, with six bladed rotors at the end of an X-shaped structure. Two small propellers with variable pitch were used for thrust and yaw control. The vehicle used collective pitch control. Built by the US Air Service, it made its first flight in October 1922. About 100 flights were made by the end of 1923. The highest it ever reached was about 5 m (16 ft 5 in). Although demonstrating feasibility, it was underpowered, unresponsive, mechanically complex and susceptible to reliability problems. Pilot workload was too high during hover to attempt lateral motion.\[1\]

Convertawings Model A Quadrotor (1956)
This unique helicopter was intended to be the prototype for a line of much larger civil and military quadrotor helicopters. The design featured two engines driving four rotors through a system of v belts. No tailrotor was needed and control was obtained by varying the thrust between rotors.\[4\] Flown successfully many times in the mid-1950s, this helicopter proved the quadrotor design and it was also the first four-rotor helicopter to demonstrate successful forward flight. Due to a lack of orders for commercial or military versions however, the project was terminated. Convertawings proposed a Model E that would have a maximum weight of 42,000 lb (19 t) with a payload of 10,900 lb (4.9 t) over 300 miles and at up to 173 mph (278 km/h).

Curtiss-Wright VZ-7 (1958)
The Curtiss-Wright VZ-7 was a VTOL aircraft designed by the Curtiss-Wright company for the US Army. The VZ-7 was controlled by changing the thrust of each of the four propellers.

Recent developments

In the last few decades, small scale Unmanned Aerial Vehicles (UAVs) have become more commonly used for many applications. The need for aircraft with greater maneuverability and hovering ability has led to current rise in quadcopter research. The four-rotor design allows quadcopters to be relatively simple in design yet highly reliable and maneuverable. Cutting-edge research is continuing to increase the viability of quadcopters by making advances in multi-craft communication, environment exploration, and maneuverability. If all of these developing qualities can be combined together, quadcopters would be capable of advanced autonomous missions that are currently not possible with any other vehicle.\[5\]

Some current programs include:
• The Bell Boeing Quad TiltRotor concept takes the fixed quadcopter concept further by combining it with the tilt rotor concept for a proposed C-130 sized military transport.

• Aermatica Spa's Anteos is the first rotary wing RPA (remotely piloted aircraft) to have obtained official permission to fly in the civil airspace, by the Italian Civil Aviation Authority (ENAC), and will be the first able to work in non segregated airspace. [6]

• AeroQuad and ArduCopter are open-source hardware and software projects based on Arduino for the DIY construction of quadcopters. [11]

• Parrot AR.Drone is a small radio controlled quadcopter with cameras attached to it built by Parrot SA, designed to be controllable with by smartphones or tablet devices. [7] In June 2013, at the Paris Air Show, Parrot announced they have sold over 500,000 AR.Drone quadcopters. [8]

Uses

Research platform

Quadcopters are a useful tool for university researchers to test and evaluate new ideas in a number of different fields, including flight control theory, navigation, real time systems, and robotics. In recent years many universities have shown quadcopters performing increasingly complex aerial manoeuvres. Swarms of quadcopters can hover in mid-air, in formation, autonomously perform complex flying routines such as flips, darting through hula-hoops and organise themselves to fly through windows as a group. [9][10]

There are numerous advantages for using quadcopters as versatile test platforms. They are relatively cheap, available in a variety of sizes and their simple mechanical design means that they can be built and maintained by amateurs. Due to the multi-disciplinary nature of operating a quadcopter, academics from a number of fields need to work together in order to make significant improvements to the way quadcopters perform. Quadcopter projects are typically collaborations between computer science, electrical engineering and mechanical engineering specialists. [9]

Because they are so manoeuvrable, quadcopters could be useful in all kinds of situations and environments. Quadcopters capable of autonomous flight could help remove the need for people to put themselves in any number of dangerous positions. This is a prime reason that research interest has been increasing over the years. [9]

There are some world-class engineering research laboratories currently developing more advanced control techniques and applications for quadcopters. These include mainly MIT's Aerospace Controls Lab, [11] ETH's Flying Machine Arena, [12] and University of Pennsylvania's General Robotics, Automation, Sensing and Perception (GRASP) Lab. [13]

Military and law enforcement

Quadcopter unmanned aerial vehicles are used for surveillance and reconnaissance by military and law enforcement agencies, as well as search and rescue missions in urban environments. [14] One such example is the Aeryon Scout, created by Canadian company Aeryon Labs, [15] which is a small UAV that can quietly hover in place and use a camera to observe people and objects on the ground. The company claims that the machine played a key role in a drug bust in Central America by providing visual surveillance of a drug trafficker's compound deep in the jungle (Aeryon won't reveal the country's name and other specifics). [16]
**Commercial**

The largest use of quadcopters has been in the field of aerial imagery. Quadcopter UAVs are suitable for this job because of their autonomous nature and huge cost savings. Capturing aerial imagery with a quadcopter is as simple as programming GPS coordinates and hitting the go button. Using on-board cameras, users have the option of being streamed live to the ground. Many companies have used this for real estate photography to industrial systems inspection. Various organizations are taking advantage of the quadcopter's closed-circuit television capabilities and ability to provide an eye in the sky to the action below.

**Flight control**

Each rotor produces both a thrust and torque about its center of rotation, as well as a drag force opposite to the vehicle's direction of flight. If all rotors are spinning at the same angular velocity, with rotors one and three rotating clockwise and rotors two and four counterclockwise, 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 maneuver 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. The quadcopter design remains inherently in balance for yaw, even as the primary control inputs are changed, thus is easier to learn to fly. In practice, high-end quadcopters today also use on-board gyroscopes to stabilise yaw more precisely.

Quadcopters may use either the ‘diamond’ or ‘square’ layouts of their rotors. The diamond pattern is slightly easier to understand, as each control axis relies on a single pair of rotors and the others are unaffected. With the addition of a simple control mixer though, the square pattern operates just as easily. Like the V tail of some fixed-wing aircraft, movements of pure pitch or pure roll then rely on a combined input to the two diagonal axes.
A quadrotor hovers or adjusts its altitude by applying equal thrust to all four rotors.

A quadrotor adjusts its yaw by applying more thrust to rotors rotating in one direction.

A quadrotor adjusts its pitch or roll by applying more thrust to one rotor and less thrust to its diametrically opposite rotor.

Mechanical

The main mechanical components needed for construction are the frame, propellers (either fixed-pitch or variable-pitch), and the electric motors. For best performance and simplest control algorithms, the motors and propellers should be placed equidistant.\(^{[19]}\) Recently, carbon fiber composites have become popular due to their light weight and structural stiffness.\(^{[20]}\)

The electrical components needed to construct a working quadcopter are similar to those needed for a modern RC helicopter. They are the Electronic Speed Control module, on-board computer or controller board, and battery. Typically, a hobby remote control is also used to allow for human input.\(^{[21]}\)

Notes

[5] Coming of Age of Quadrotors (http://illumin.usc.edu/162/the-quadrotors-coming-of-age)
[16] For a V tail, the relevant control axes are pitch and yaw.
[19] Basic Assembly Kit for a Quadrotor (http://www.instructables.com/id/Quadrotor)
References

External links

- ETH Zurich Research on Quadrotors (http://www.idsc.ethz.ch/Research_DAndrea/Flying_Machine_Arena)
- UPenn GRASP Laboratory (https://www.grasp.upenn.edu/research/highlights)
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