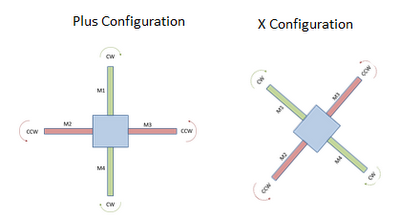
ABSTRACT

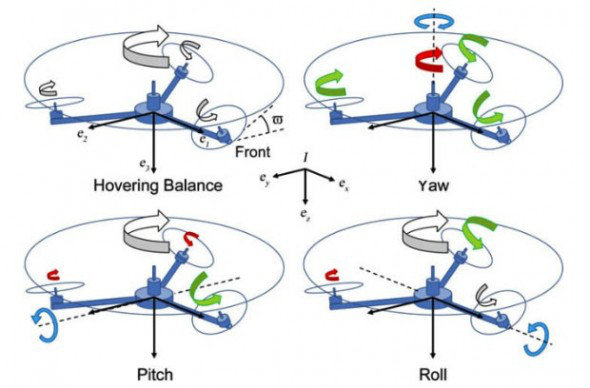
 The goal of our group’s project is to design and build an autonomous quadcopter from scratch. This means going through the process of researching previous models, performing calculations, purchasing individual parts, testing those parts, designing the final product, designing an Arduino based controller, and finally fitting everything together. All this is to be done with the minimum amount of outside help we can manage (i.e. not using pre-determined code, not buying a boxed set of materials). After deciding how big we wanted our quadcopter to be and purchasing the appropriate parts there were four primary design steps on the way to the final product. First we had to learn to control and program the ESCs using an Arduino. Next we used a spring-mass test setup to determine a relationship between force and displacement, and thereby determined the relationship between force and pulse width of the signal going into the ESC. Once we felt comfortable with our ability to communicate with the ESC we used another test setup comprised of a rotating bar suspended between two beams to practice stabilizing the system in 1 degree of freedom (roll). Following success stabilizing in 1-DoF we designed our final test setup comprised of two vertical bars to which the body of the quadcopter is attached. Using this rig we were able to test and stabilize in 2-DoF (roll and pitch), have the quadcopter translate vertically, and introduce small disturbances for which the system controller was able to compensate automatically.

INTRODUCTION TO QUADCOPTERS

**Introduction to Quadcopters** Over the last few years we have seen a massive growth in the manufacture and sales of remote control airborne vehicles known as **Quadcopters**. These **Unmanned Aerial Vehicles** have four arms and fixed pitch propellers which are set in an X or + configuration with X being the preferred configuration.

[](https://droneflyers.files.wordpress.com/2014/03/quadcopter-configurations.png)**Quadcopter Configurations**

They are sometimes referred to as **Drones**, **Quadrotors** or **Quadrocopters**. In the standard format two propellers will spin in a clockwise direction with the other two spinning in an anticlockwise direction allowing the craft to vertically ascend, hover in the air and fly in a designated direction. The Quadcopter is a simple format with very few moving parts and has rapidly become a favourite vehicle for remote control enthusiasts and is widely being used as an effective Aerial photographic platform. A large majority of the **Quadcopters** were originally built by hobbyists who understood the simplicity of the vehicle. By adding four motors and four propellers to a lightweight frame constructed of light wood, carbon fibre, or fibreglass then connecting it to a remote control transmitter via a small control board fitted with a gyroscopic stabilization system and connected to a Lipo battery these craft were relatively simple to construct. Experimentation has led to the configuration of variations of the Quadcopter by using different amounts of arms we have seen Tricopters, Hexacopters and Octocopters (with eight arms). Other configurations include a Vtail and an Hframe variation.

[](https://droneflyers.files.wordpress.com/2014/01/triquad_control1.jpg)**Tricopter Configuration**

The rapid advances in computing power, the efficiency of the coreless or brushless motors, smaller microprocessors the development of batteries and gyroscopic and accelerometer technology has all led to a proliferation of Quadcopter designs. The first Quadcopters were not designed for acrobatic flight as the development was concentrated on simple stable flight patterns but now this has all changed.

LITERATURE SURVEY

**Quadcopter history**

**Etienne Oehmichen** was the first scientist who experimented with rotorcraft designs in the 1920s. Among the six designs he tried, his second multicopter had four rotors and eight propellers, all driven by a single engine. The Oehmichen 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 was 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. Later, it completed the first 1 kilometer closed-circuit flight by a rotorcraft.

After Oehmichen, 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. 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. 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.

**Convertawings Model A Quadrotor** (1956) 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 with wings added for additional lift in forward flight. No tail rotor was needed and control was obtained by varying the thrust between rotors. 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 (19,000 kg) with a payload of 10,900 lb (4,900 kg).

**Recent Development**

Recent quadrotors or quadropters which are being manufactured and used in aerospace industry are listed below:

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

         AeroQuad is an open-source hardware and software project which utilizes Arduino boards and freely provides hardware designs and software for the DIY construction of Quadcopters.

         ArduCopter is an open-source multicopter UAV. Based on Arduino, it supports from four to eight motors, as well as traditional helicopters, and allows fully autonomous missions as well as RC control.

         OpenPilot is a model aircraft open-source software project.

         Parrot AR.Drone is a small radio controlled quadcopter with cameras attached to it built by Parrot SA, designed to be controllable with iOS or Android devices. Parrot AR.Drone 2.0 carries a HD 720P camera and more sensors, such as altimeter and magnetometer.

**Literature Reviewed**

As Arduino is the flight controller board for our quadropter we have taken help of Aeroquad library for the implementation of various sensors in the board. Aeroquad library is available freely under GNU liscence and is widely used for sensor integration using Arduino boards. ‘**Getting Started with Arduino**’ written by **Massimo Banzi** proved to be very helpful in understanding Arduino concepts and its usage. Apart from ebooks we also review some scholarly articles under Quadcopter design title which are listed as below:

         Zhang, Y., et al. "Development of the model and hierarchy controller of the quad-copter." Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering 222.1 (2008): 1-12.

         Sa, Inkyu, and Peter Corke. "Estimation and control for an open-source quadcopter." Proceedings of the Australasian Conference on Robotics and Automation 2011. 2011.

         Bemporad, Alberto, C. A. Pascucci, and Claudio Rocchi. "Hierarchical and hybrid model predictive control of quadcopter air vehicles." Analysis and Design of Hybrid Systems. Vol. 3. No. 1. 2009.

DESIGN METHODOLOGY

Quadcopter is a kind of unmanned aerial vehicle (UAV).

UAV can generally be defined as a device used or

intended to be used for flight in the air that has no on-

board pilot [2].These devices are sometimes referred to

as drones, which are programmed for autonomous

flight, and remotely piloted vehicles (RPVs), which are flown remotely by a ground control operator [3].This

fact in many cases can result in high maintenance and

deployment costs particularly speaking in the industrial

domain applications. Some applications implement an

autonomous flight mode, however the autonomy here is

intended as a simple path planning through several

given points.

Quadcopter can be used in applications such as aerial

recognition, search-and-rescue, industrial monitoring

missions among others. For instance, the Predator and

Reaper, two drone built by General Atomics, which

were used by the United States Air Force to recognition

and combat over several countries [4]. A more pacific

application of UAVs is monitoring agriculture as done by

the company AGX Tecnologias that developed several

configuration of aerial vehicle to map different varieties

of plantations [5].

Dimensions of quadcopters can vary from the size of an

insect to a size of a professional aerial vehicle.

Dimensions differ according to the type of application in

which this UAV are going to be implemented and the

equipment they are taking. For example in application

where there is a need for detecting toxic substances in

the air, quadcopter needs to be equipped with sensors

(in most cases they are light) so the quadcopter can be

small. In military applications, where the quadcopter

needs to be equipped with camera, sensors, and

sometimes weapons, quadcopter needs to be much larger.

Camera and adequate software can be used to provide

imaging-based automatic inspection and analysis for

such applications as automatic inspection, process

control, and robot guidance in industry [6]. A

quadcopter is a multirotor UAV 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 rotors (vertically

oriented propellers). One of applications is in

Amazon.com Inc., the world’s largest online retailer.

They announced their Prime Air service which is a new

shipment system where a multi-rotor delivers packages

to customers [7].

A quadcopter uses four propellers for trust and has

them configured in either a cross or plus format. The

quadcopter robot can take off and land vertically which

is a big advantage as it lowers the requirements for

alanding platform. Also, it allows the quadcopter to

hover in place with considerable stability.

Hover stability prevents the quadcopter from crashing in

the event of strong wind or due to its weight. Fig. 1

shows the six degrees of freedom of the quadcopter. In

Fig. 1(a) (birds eye view), x and y represents the

translational motion along the x- and y-axes

respectively and ψ represents yaw, the rotational

motion about the z-axis, while in Fig. 1(b) (frontal view),

θ represents roll, the rotational motion about the x-

axis,φ represents pitch, the rotational motion about the

y-axis and z represents the translational motion in the

direction per pendicular to ground. The label ‘1’ signifies

the front propeller [8].

With a hover control unit, the quadcopter can hover at a

constant height z (see Fig. 1(b)), with its roll and pitch

angles stabilised by the gyroscope. The person at the command base will only need to control the

quadcopter’s motion along the x- and y-axes and also

its rotation about the z-axis (to turn corners), reducing

the degree of complexity from six to only three.

2.1

Quadcopter model

Quadcopters use 2 sets of identical fixed pitched

propellers; 2 clockwise (CW) and 2 counter-clockwise

(CCW). These use variation of RPM to control lift and

torque. Control of vehicle motion is achieved by altering

the rotation rate of one or more rotor discs, thereby

changing its torque load and thrust/lift characteristics.

The front and the rear propellers rotate counter-

clockwise, while the left and the right ones turn

clockwise. This conﬁguration of opposite pairs

directions re-moves the need for a tail rotor (needed

instead in the standard helicopter structure). Fig. 2

shows the structure model in hovering condition, where

all the propellers have the same speed [9].

Figure 2.

The quadcopter structure model in hovering

condition [9]

In Fig.2 a ﬁxed-body B-frame of quadcopter is shown

(X

B

, Y

B

, Z

B

). Also the angular speed of the propellers is

represented. In addition to the name of the velocity

variable, for each propeller, two arrows are drawn: the

curved one represents the direction of rotation, the

other one represents the velocity. This last vector

always points upwards hence it doesn’t follow the right

hand rule (for clockwise rotation) because it also

models a vertical thrust and it would be confusing to

have two speed vectors pointing upwards and the other

two pointing downwards. All four propellers rotate at the

same speed which is represented as Ω [rad s

-1

] to

counterbalance the acceleration due to gravity [9].

Even though the quadcopter has 6 DOF, it is equipped

just with four propellers. Thanks to its structure, four

best controllable variables can be chosen related to the

four basic movements which allow the quadcoper to

reach a certain height and attitude. It follows the

description of these basic movements:

• Throttle (U

1

[N]) - increasing (or decreasing) all the

propeller speeds by the same amount. It leads to a

vertical force which raises or lowers the quadcopter.

If the quadcopter is in horizontal position, the vertical

direction of the inertial frame coincide. Otherwise the

provided thrust generates both vertical and

horizontal accelerations in the inertial frame.

• Roll (U

2

[N m]) - increasing (or decreasing) the left

propeller speed and by decreasing (or increasing)

the right one. It leads to a torque with respect to the

X

B

axis (Fig. 2) which makes the quadcopter turn.

The overall vertical thrust is the same as in hovering,

hence this leads only to a roll angle acceleration (in

ﬁrst approximation).

• Pitch (U

3

[N m]) - similar to the roll and is provided

by increasing (or decreasing) the rear propeller

speed and by decreasing (or increasing) the front

one. It leads to a torque with respect to the Y

B

axis

(Fig. 2) which makes the quadcopter turn. The

overall vertical thrust is the same as in hovering,

hence this leads only to a pitch angle acceleration

(in ﬁrst approximation).

• Yaw (U

4

[N m]) - increasing (or decreasing) the front-

rear propellers’ speed and by decreasing (or

increasing) that of the left-right couple. It leads to a

torque with respect to the Z

B

axis (Fig. 2) which

makes the quadcopter turn. The yaw movement is

generated thanks to the fact that the left-right

propellers rotate clockwise while the front-rear ones

rotate counter clockwise. When the overall torque is

unbalanced, the quadcopter turns on itself around

Z

B

. The total vertical thrust is the same as in

hovering, hence this leads only to a yaw angle

acceleration (in ﬁrst approximation) [9].

2.2

Control algorithms

The PID (Proportional-Integral-Derivative) control

algorithm has been considered and implemented in

literature to control the hover altitude of the quadcopter

[10], [11]. PID control is a type of linear control that is

widely used in the robotics and automation industry

[12]. The PID algorithm is popularly used mainly

because [13]:

• It has a simple structure

• It provides good performance

• It can be tuned even if the specific model of the

controlled plant or system is not available

A PID controller functions by calculating the error, or

difference between a measured output and a desired

setpoint and adjusts the system control inputs such that

the calculated error is minimised. The PID algorithm

consists mainly of three control parameters, P –

Proportional, I – Integral and D – Derivative. The

mathematical expression of the discrete-time PID

algorithm is given in (1). P determines the reaction to

the current error, I determines the reaction based on a

sum of recent errors while D responds to the rate at

which the error has been changing.

Calculation of the control input by control algorithms

such as PID control may return a control input gain

which may be too high for the quadcopter system. This

results in a large control input magnitude which may be

out of the limits recognisable by the system. To solve

this problem, the linear quadratic regulation (LQR)

method can be employed. LQR is a form of linear

optimal control regulation which aims to reduce the

magnitude of the control input without affecting the

performance of the control algorithm [14]. The LQR

algorithm is used to obtain the parameter settings that

will minimise the undesired deviations (in this research,

altitude) while at the same time limiting the energy

expended by the control action by using a mathematical

algorithm that minimises a cost function or performance

index with weighting factors. The cost function or

performance index refers to the sum of deviations of

measured values from its desired values [14]. For a

discrete-time LQR, the performance index is defined as

(1). By adjusting the weight parameters Q and R, the

optimal control sequence that minimises the

performance index is given by (2) [8].

)(

0k

T

kk

N

k

T

kRuuQxxJ +=

∑

=

(1)

1−

−=

kkk

xFu

(2)

The steps involved in the empirical methodology to

obtain control parameters are shown in Fig. 3.

Figure 3. Steps in empirical methodology

Different approaches have been developed for

formation of flight control. Linear formation flight

controller has been discussed in [15], [16].

The advantage of the linear control is that it is intuitive

and easy to synthesize, but it cannot handle the

constraints directly and may not be valid for large

operation range since it is designed around a fixed

operating point.

Some researchers addressed the nonlinear formation

flight control problem by using feedback linearization

[17] and adaptive control [18], [19]. Although these

nonlinear control methods can deal with the unmodelled

dynamics, they cannot handle the constraints directly

and the implementation of such controller may result in

ill-defined control inputs.

3. HARDWARE COMPONENTS OF QUADCOPTER

Each quadcopter can have a very different hardware

component which mostly depends on application in

which it will be implemented. Standard components are:

microcontroller, sensors, motors, Global Positioning

System (GPS) power supply and telemetry devices.

Basic component of each quadcopter is frame. The

arms and centre plate of the quadcopter frame is in

most cases are made of carbon fiber. Connections

between the centre plates and arms, as well as the

motor mounts can be made of aluminium. The modular

integration of the frame allows components to be

replaced easily if necessary. The frame, illustrated in

Fig. 5, is 485 cm long from motor to motor and weighs

approximately 450 g. The propulsion system is mounted

directly onto this frame.

Another important part of quadcopter is propulsion unit.

The propulsion unit for the quadrotor consists of four brushless DC motors and four electronic speed

controllers. The power source for the system can be cell

lithium polymer battery. Propellers mounted on the

motors must be several cm lengths and have a fixed

pitch angle. This propulsion configuration allows safe

operations of the frame and ensures excellent lift and

thrust performance for all of the flight.

Beside microprocessor and inertial measurement unit

with accelerometers, magnetometer and gyroscopes

there is a need for external sensors.

In most cases, as external sensor, infra-red sensors

and ultrasonic sensor can be used. They can be used

for the collision avoidance schemes and for altitude

control. GPS module is another type of equipment which

is mandatory for navigation purposes.

TOOLS USED

* Soldering iron and solder. You will need to solder the motors, ESC, PDB/harness and a battery plug. I used 30W iron and I felt it was to small for the power cables.
* Helping hand/3rd hand tool – you want the wires as short as possible, which means the soldering is harder than usual. Without the [helping hand tool from Maplin](http://www.maplin.co.uk/p/helping-hands-with-large-magnifier-n30ch) I would be sitting here until next Christmas.
* Heat gun. I didn’t feel using a cigarette lighter would be good for the machine. Heat gun is the cleanest way to shrink the shrink wrap. Go PRO and buy one!
* Cable cutters
* Screwdrivers
* Hex keys
* Small spanners for the frame and propeller nuts. I used pliers instead.
* Computer with internet access.
* Multimeter – to check for the soldering work before connecting a real battery.

IMPLEMENTATION

Quadcopters are uninhabited or unmanned aerial vehicles which are widely being used in modern aerospace industry. The wide area of operation and high maneuverability makes quadropter even more useful. Quadcopters are used in scientific research, geological survey, aerial photography, weather sensing, spying, and reconnaissance.

Pick and drop

This is the modern era application of drones, they can carry weights up to certain limit and

delivery them to the destination. Best example amazon and DHL are considering drone based

delivery services for their produc

*(PDF) Quadcopter*. Available from: <https://www.researchgate.net/publication/305299002_Quadcopter> [accessed Nov 13 2018].

Toys for children

Micro or mini drones are specially designed for kids that are easy to control and use.

• Air inspection

Drones are used in aircraft companies in inspecting the aircraft before takeoff & landing

*(PDF) Quadcopter*. Available from: <https://www.researchgate.net/publication/305299002_Quadcopter> [accessed Nov 13 2018].

RESULTS AND CONCLUSION

Quadcopter is a special kind of vehicle, which can be

implemented in different applications. In this paper

basic principles of quadcopter design as well as current

applications are represented. In the future applications,

quadcopter could be used for a variety of new policing

functions. Quadcopter could be used for safety

inspections, perimeter patrols around prisons and

thermal imaging to check for cannabis being grown in

roof lofts and other not easy to access locations. The

police could use them to capture number plates of

speeding drivers, for detecting theft from cash

machines, railway monitoring, combat fly-posting, fly-

tipping, abandoned vehicles, waste management.

Future research will be in field of search and rescue. In

future an effort will be directed to development of a

system for defining evacuation/safe path in case of

natural disasters and accidents. The system will

consists of quadcopter which is equipped with a camera

to capture different terrain (land or water) and a

processing unit for processing the recorded condition

which is placed on the vehicle/vessel or in form of

handheld device. In addition to the situations of natural

disasters and accidents it is possible to use this system

in cases of climatic changes that affect the safety and

health of the population, or in cases where it is

endangering the functionality of different economic

systems.

FUTURE SCOPE

Future of a quad-copter is quite vast based on various application fields it can be applied to.

Quad-copter can be used for conducting rescue operations where it’s humanly impossible to

reach. In terms of its military applications it can be more widely used for surveillance purposes,

without risking a human life. As more automated quad-copters are being developed, there range

of applications increases and hence we can ensure there commercialization. Thus quad-copter

can be used in day to day working of a human life, ensuring their well-being.

*(PDF) Quadcopter*. Available from: <https://www.researchgate.net/publication/305299002_Quadcopter> [accessed Nov 13 2018].

COST ANALYSIS

The cost estimation per each quadquopter:

**XT60 male connectors- 2pcs ₹137.00**

**IMAX** B6AC **charger/discharger**    **₹2,575.00**

**FS IA6 6CH 2.4GHz radio receiver**   **₹1,338.00**

**Orange 3000mAh LI-po battery**   **₹1,050.00**

**Q450 Quadquapter frame (PCB+ version with**

**Integrated PCB) ₹1177.76**

**4xRACESTAR RS30A ESC**   **₹2,218.26**

**External Brushless BEC 5v Reciever power**

**Supply**  **₹175.38**

**GEMFAN 1045 nylon propeller Race start**

**BR 2212 1000KV2-4S**   **₹179.54**

**Brushless motor for RC Models generic**

**Mini kk2, kk2.1,kk2.15**   **₹1,300.44**

**Kk multi-Rotor Flight Controller**   **₹1,800**

**Other required items  ₹1245**

**TOTAL COST :13,000(Approx)**

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The links and websites used for reference:

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