Design of Quadcopter in Reconnaissance

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Design of Quadcopter in Reconnaissance

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Abstract: The military use of Unmanned Aerial Vehicles (UAVs) has grown because of their ability to operate in dangerous locations while keeping their human operators at a safe distance. The UAVs provide a reliable long duration, cost effective, platform for reconnaissance. They have grown to become an indispensable tool for the military. The question we posed in this paper was whether small UAVs also had utility in military and commercial as well as industrial applications. We postulated that smaller UAVs serve more tactical operations such as searching a village or a building for enemy positions. They should be able to handle military tactical operations as well as the emerging commercial and industrial. To validate this proposal, we considered many different UAV designs before we settled on creating a quadcopter. The payload of our quadcopter includes a camera and telemetry that will facilitate to watch video from quadcopter on a screen located few meters away.

Keywords: Quadcopter, Unmanned Aerial Vehicle (UAV), Arduino, Surveillance, vertical take-off and landing (VTOL).

1. INTRODUCTION

The development of small autonomous unmanned aerial vehicles is an area of interest that many researches wish to explore. There is currently a large range of projects and research topics emerging in this field.

Autonomous aerial vehicles are true mechatronic systems that combine elements of mechanical, electronic, electrical, software and control engineering.

Preliminary research has shown that the most versatile and mechanically easy to construct autonomous aerial vehicle is a quadrotor helicopter. This is due to the fact that quadrotors can be fully controlled solely by varying the speed of the four rotors and no mechanical linkages are required to vary the rotor blade pitch angles as with a conventional helicopter. Quadrotor aerial robot is an automatic system which is an unmanned VTOL (vertical take-off and landing) helicopter.

The quadcopter consist of four rotors constituted at the four end of the cross intersection. Each rotor/propeller is driven by a brushless motors [1] attached to electronic motor controllers in order to communicate with the microcontroller, with which we can control the speed of each individual motor. The speed of each motor will determine the upward and downward acceleration. We can then generate algorithms using an on board accelerometer to measure the pan and tilt of the quadcopter, which the microcontroller would read and then appropriately control each motor. Using a four motor quadcopter design we are able to change directions, elevation, and tilt by simply manipulating how much voltage goes into the motors while it is in the air. We can also integrate an array of sensors onto our quadcopter that can measure the temperature and guide it away from obstacles.

Quad-rotor comprises of four motors in total, with two pairs of counter-rotating, fixed-pitch blades located at the four corners. Quadcopter do not require complex mechanical control linkages for motor actuation, relying instead on fixed pitch rotors and using variation in motor speed for vehicle control. It simplifies both the design and maintenance of the vehicle. The use of four rotors ensures that individual rotors are smaller in diameter than the equivalent main rotor on a helicopter, relative to the airframe size. The individual rotors, therefore, store less kinetic energy during flight [2].

In a quad-rotor there are four rotors with fixed angles which represent four input forces that are basically the thrust generated by each propeller. The collective input is the sum of the thrusts of each motor.

The quadcopter will implement the use of a wireless module in order to communicate with a base station.

1.1 Quadcopter theory

The Quadcopter uses four propellers, each controlled by its own motor and electronic speed controller. Accelerometers will measure the angle of the Quadcopter in terms of X, Y, and Z axis and accordingly adjust the RPM of each motor in order to self-stabilize its self. The Quadcopter platform provides stability as a result of the counter rotating motors which result in a net moment of zero at the centre of the Quadcopter.

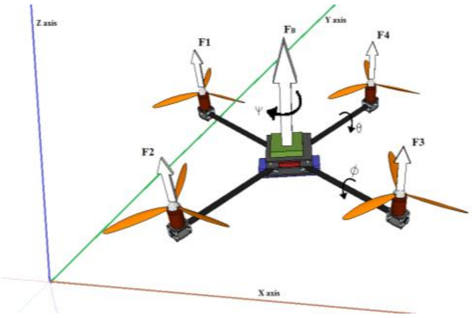


Fig.1 Net momentum

Using this principle we are able to adjust the speed (RPM as a function of the voltage provided to the motor) of each individual motor in order to correctly manipulate Quadcopter's yaw, tilt, and roll. Tilt and roll can be controlled by changing the speed of the appropriate motors, while yaw control involves delicate balancing of all four motor functions in order to change the moment force applied to the quad. Controlling the Quadrotor involves four different states [3]:

U1 - Upward motion z-direction: (figure 2) with respect to the body. This motion is provided by the thrust generated by all four motors rotating with the same angular velocity.

U2 - Roll motion Φ: (figure 3) this motion is attained by the force differential between the thrust generated by the right and the left propellers.

U3 - Pitch motion θ: (figure 4) this motion is attained by the force differential between the thrust generated by the front and the rear propellers.

U4 - Yaw motion ψ: (figure 5) this motion is attained by controlling two sets of flaps placed underneath the side propellers to redirect a small component of the normal-to-body thrust force in the horizontal plane. The force components act in opposite directions which create a moment-couple about the vertical axis of the body.

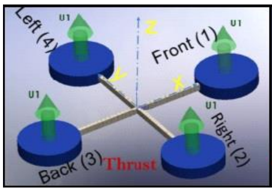


Fig.2 Thrust

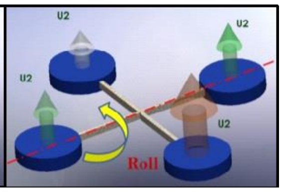


Fig.3 Roll

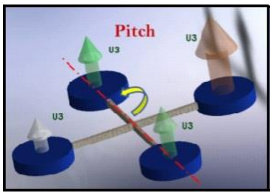


Fig.4 Pitch

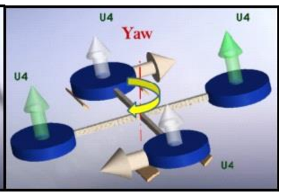


Fig.5 Roll

2. LITERATURE REVIEW

Many robotics researchers have exhibited impressive navigation and control achievements with quadcopter platforms in indoor and outdoor environments. Pounds et al. presented fundamental dynamics analysis and control approaches through the design of a large-size quadrotor with total weight of 4kg and capable of lifting a 1kg payload which was deemed necessary for the computers and sensors of the time [4], [5]. Bouabdallah and Siegwart accomplished impressive results in control and state estimation with a quadcopter platform and a ground station. Image data was sent to the ground station, processed, and commands were transmitted back to the flying vehicle over a radio communications link [6].

Javier, Masoud and Bruce presented the usability of quadcopter as safety inspection tool in industries. They focused on the construction industry. Their study proposed the use of a quadcopter to fly over the construction jobsite and provide the safety manager with real time information about what is happening on the jobsite. Also through the communication tools embedded in the quadcopter, safety manager can interact directly with workers [7].

Tsubasa, Andrew, Ehrich, Eric, Paul and John proposed the concept of non-destructive evaluation of structures like bridges, where using equipment mounted on a highly stable and mobile UAV like quadcopter is more efficient and economical. The stability issue is addressed immediately by the quadcopter concept, however there was a need of a structure that was stiff, lightweight and less complex [8].

Recent case of using quadcopter for civilian application is when tsunami stuck the Fukushima nuclear power plant in Japan on the 11th March, 2011.Dut to very unsafe conditions at the plant, Tokyo Electric Power (TEPCO) used a US-made micro aerial vehicle to photography the nuclear plant from above. The flying robot had already had already been used by the US military to find roadside bombs in Iraq [9].

The practical use of a quadcopter was sited in New Zealand to examine the front of the Roman Catholic Cathedral in Christ church that was damaged in the 22nd February, 2011 earthquake[10].

Universities and research institutions have started using this quadcopter as an experimental platform in different researches such as autonomous surveillance and navigation [11], human-machine interaction [12], and even as a sport assistant by providing athletes with external imagery of their actions [13].

3. SYSTEM DESCRIPTION

The control signal generated by remote on base station is wirelessly sent via Xbee Coordinator to another Xbee Router connected on the quadcopter. The microcontroller decodes the data frame sent and process it. The Arduino also has input signals from sensors in IMU board. The IMU board consists of 3-axis gyroscope and 3-axis accelerometer on it. Data from these sensors will be helpful in stabilizing and balancing the quadcopter. The Arduino is governed by the programme written in its memory. According to the data received from the remote via Xbee and from the sensors, the Arduino sends

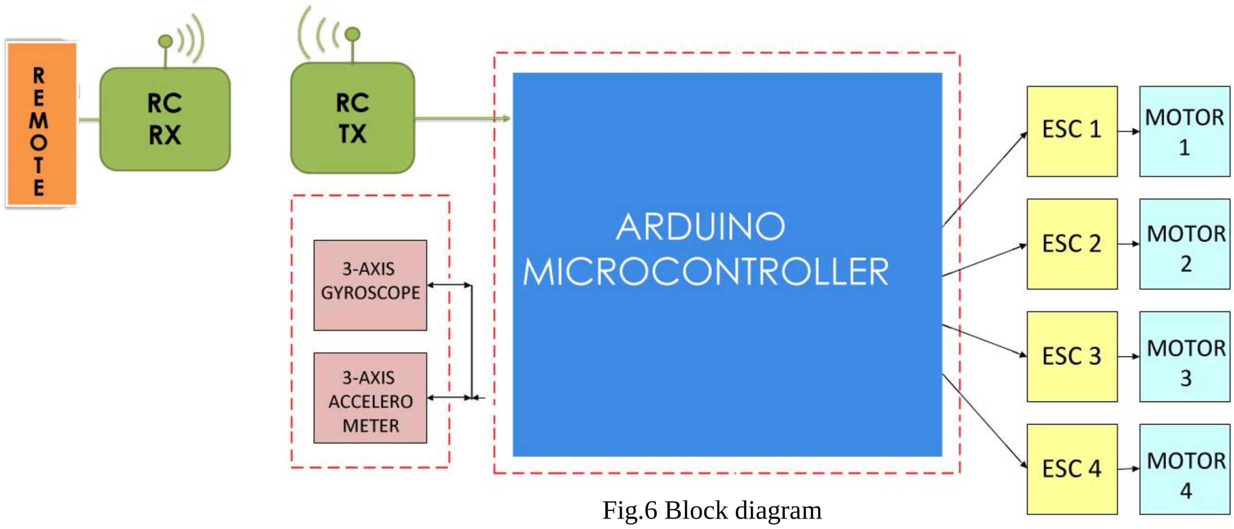


Fig.6 Block diagram

appropriate voltage to the ESCs. This would be achieved by the PWM channels available in it.

Yaw motion is achieved by supplying more voltage to M1 and M3 which moves the Quadcopter in left direction. Supplying more voltage to M2 and M4 which moves the Quadcopter in right direction.

3.1 Frame design and construction

The components of our quadcopter are framed together on a frame. The main design consideration for the frame, as for most aircraft, is minimising weight. Because this is a multi-rotor vehicle a separation gap of 25.4 mm must be maintained between propeller tips to avoid wake interference [14]. Additional considerations specifically for this project are robustness and the ability to easily adjust and mount new devices.

The early attempts at designing a basic layout of the quadcopter began with an approximate parametric designed structure for analysis and procurement of components. We conceptualized the design using Google Sketchup.

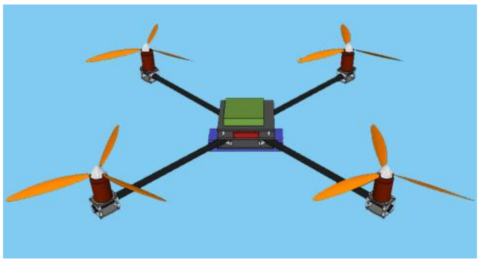


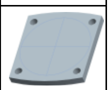
Fig.7 Conceptual design

Pro-E offers a range of tools to enable the generation of a complete digital representation of the product being designed. This section shows and highlights the final configuration that will be fabricated for each quadcopter assembly, the weight of the total quadcopter (less batteries, and other components) as well as the weight of each component/subassembly consumes of the entire structure.

3.2 First approach

The first design Quadcopter consisted of a circular rod, clamps, motor base etc. Detailed description of each component is shown in the table below.

Table1. First design component details

Sr No	Component	Dimensions (l*b*h mm)	Mass (gm.)/ quantity	Image
1	Circular hollow section	300*12.8*12.2	9.8/4	
2	Plate	100*100*3	83.8/3	
3	Clamps	30*8*8	4.17/16	
4	Motor base	30*30*3	7.9/8	
5	Studs	15*6	1.18/4	

The components listed above were assembled in pro-e software and mechanical analysis was carried out. The whole assembly of quadcopter is shown in the figure 7 below.

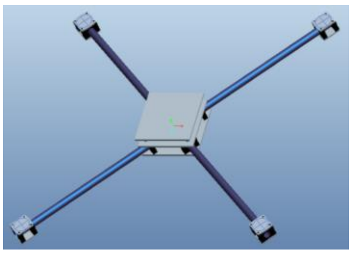


Fig.8 First chassis design

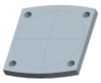
Technical details of the first assembly:

- Volume = 1.7627822 x 10^5 mm^3
- Surface area = 2.1542058 x 10^5 mm^2
- Average density = 2.7935544 x 10^6 kg/mm^3
- **Mass = 4.9244280 x 10^{-1} kg**

3.3 Final design

The second design consisted of a hollow C-section aluminium arms, motor base etc. The weight of other electrical components is constant hence the changes are made in the chases of the Quadcopter. The weight was reduces to a considerable degree. The circular section aluminium arm needed extra clamps and motor bases to hold the motors in horizontal position. Detailed description of each component is shown in the table below.

Table2. Second design component details

Sr No	Component	Dimensions (l*b*h mm)	Mass (gm.)/ quantity	Image
1	C-shaped hollow section	200*10*10	16.7/4	
2	Plate	100*100*3	83.8/3	
4	Motor base	30*30*3	7.9/8	

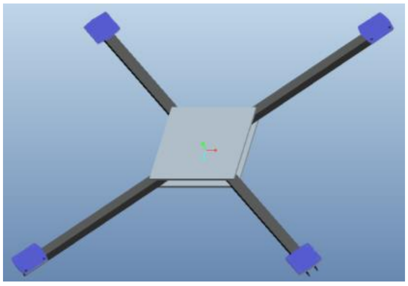


Fig.9 Second chassis design

Technical details of the second chassis:

- Volume = 9.5324694 x 105 mm3
- Surface area = 1.0168902 x 105 mm2
- Average density = 2.7935544x 106 kg/mm3
- **Mass = 2.6629472 x 10-1 kg**

3.4 Manufactured chassis

After designing the chassis in software, we sat down to manufacture it. The manufactured cassis's mass was found to be less than the software simulated. Mass of the quadcopter chassis is **1.922 x 10-1 kg**. The figure below shows the partial assembled quadcopter. The arms are 30.5mm each and the radius of the quadcopter is 27.0mm (from the centre of the chassis to the centre of motor shaft). The chassis is made of aluminium C-section and aluminium composite material.

Fig.10 Manufactured chassis

4. Design Methodology

4.1 Sensor selection

The control and balancing of quadcopter is achieved by the use of sensors that communicate to the control system. The control system performs calculates to work out the outputs required to move the quadcopter to a desired position as well as maintain stability. In the UAV and the MAV project the size and the weight of the employed components play a dominant role, it would be preferable to develop still smaller and more lightweight attitude determination systems than the ones available on the market. Attitude determination systems normally consist of gyroscopes, accelerometers and magnetometers, whereat a device, containing gyroscopes and accelerometers, is commonly called Inertial Measurement Unit (IMU). We will be using MPU6050 breakout board, which has 3-axis accelerometer and 3-axis gyroscope. An accelerometer is an electromechanical device that will measure acceleration forces. These forces may be static, like the constant force of gravity pulling at your feet, or they could be dynamic - caused by moving or vibrating the accelerometer. A gyroscope is a device used primarily for navigation and measurement of angular velocity [15]. 3-axis gyroscopes are often implemented with a 3-axis accelerometer to provide a full 6 degree-of-freedom (DOF) motion tracking system. Gyroscopes have evolved from mechanical-inertial spinning devices consisting of rotors, axles, and gimbals to various incarnations of electronic and optical devices. In more complex systems such as the International Space Station or satellites, a combined form of the gyroscopes and accelerometers is used called the Inertial Navigation System (INS) [16].

4.2 Brushless DC motors

Brushless motors are more advantageous to quadcopter over brushed DC motor. Brushless motors have more torque per weight, have more efficiency, reduced noise factor, reliability, elimination of ionizing sparks from commutator, longer life span, more power and overall reduction of electromagnetic interface.

4.3 Propellers

Propellers transduce the rotary motion to aerodynamic lift force. Two pair of counter rotating propellers make the aerodynamic torque is zero. We will be using 11 inch diameter with a pitch of 4.7 inch/revolution.

4.4 Electronic speed control (ESC)

An ESC controls the brushless motor by converting the supplied DC from the battery into three phased AC. 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. We selected Turnigy Basic 25A v3.1 Brushless Speed Controller.

4.5 Battery (LiPo)

Lithium polymer batteries (LiPo) are increasingly popular for powering remote control aircraft; due to light weight, energy density, longer run times and the ability to be recharged. We selected Zippy 11.1V 25C 5000mah battery.

4.6 Microcontroller selection

In order to gather information from the sensors, interpret the data and send the appropriate control signals to the actuators a microcontroller is needed. Searching for the right controller to be interfaced with other components, we came across Arduino Uno which is a user friendly microcontroller board. It is based on ATmega328 with 14 digital I/O pins (of which 6 provide PWM output) and 6 analog I/O pins, 4 UARTs, a 16 MHz crystal oscillator, 1KB EEPROM and 32KB flash memory.

4.7 Lippo alarm

A Lippo alarm is an audible and visual alarm that plugs in to your battery to provide a voltage warning when in flight. This is necessary to know when to land your craft prior to engine failure due to low batteries.

4.8 Wireless camera

These very small cameras wirelessly transmit to one of our 1.2-2.4GHz receivers that come with our wireless camera packages. This will provide wireless video from a distant quadcopter to the base station.

4.9 Receiver

For radio controlled (RC) systems we need a transmitter and receiver. One or more output devices such as an ESC/motor combo or servos. These are plugged into the receiver and are usually used to spin wheels or move control surfaces such as a steering mechanism. We will be using HobbyKing HK6S 2.4GHz FHSS 6 channel transmitter and receiver.

5. CONCLUSION

The core intention of our project is to familiarize ourselves with the complete design process from engineering requirement to finished product. We aim at making a robust design of a quadcopter which can be used in the market for both military and commercial use. With the aid of our faculty advisor we have the resources and technical knowledge to successfully complete this project. We chose the quadcopter for our UAV design since it has interesting design elements and potential for marketable gains. At this point the project could go in a variety of directions since the platform seems to be as flexible. This flexibility allows changing the functions it performs and also allows integration of any technology that would prove to be useful. This project will clearly demonstrated the goals of proving that small scale UAVs are useful across a broad range of applications.

Application of a quadcopter other than reconnaissance are listed below:

- Safety inspection tool in construction industry
- Traffic monitoring
- Locating forest fires or frost conditions in farmlands
- Visual tracking and control using camera system
- Object identification and avoiding using fuzzy control
- Temperature and altitude estimation
- Weather forecasting
- Scenic photography
- Post natural disasters
- Agriculture surveying
- Crowd management
- Perimeter surveillance
- Search and rescue operations

REFERENCES

[1] Yu yali, Jiang changhong,Wu haiwei’’Back stepping Control of Each Channel for a Quadrotor Aerial Robot’’201O *International Conference on Computer, Mechatronics, Control and Electronic Engineering (CMCE).* 2009.

[2] Gabriel M. Hoffmann† Haomiao Huang‡ Steven L.Waslander§ Claire J. Tomlin Quadrotor Helicopter Flight Dynamics and Control: Theory and E+xperiment.

[3] “Modelling, Identification and Control of a Quadrotor Helicopter”, T. Bresciani, Lund University, 2008.

[4] P. Pounds, R. Mahony, and P. Corke, “Modelling and Control of a Large Quadrotor Robot,” in Control Engineering Practice, vol. 18, pp. 691 – 699, 2010.

[5] P. Pounds and R. Mahony, “Design principles of large quadrotors for practical applications,” in Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), pp. 3265 –3270, May 2009.

[6] R. S. Samir Bouabdallah, Pierpaolo Murrieri Autonomous Robots, vol. 18, Mar 2005.

[7] J. Irizarry, M. Gheisari and B. Walker, “Usability assessment of drone technology as safety inspection

tools" in Journal of Information Technology in Construction, Sept 2012.

[8] T. Iwai, A. Nunnikhoven, E. Rodger, E. Roggatz, P. Rose and J. Warning, "Quadcopter with collective and cyclic control" in Iowa State University, Project Design, Fall 2010.

[9] Honig, Z. (2011) "T-Hawk UAV enters Fukushima danger zone, returns with video." 6:48PM April 21, 2011, retrieved on April 22, 2011. http://www.engadget.com/2011/04/21/t-hawk-uav-enters-fukushima-danger-zone-returns-with-video/.

[10] Zibreg. C. (2011) "Awesome use of an iPad and the Parrot AR Drone." 8:10 June 15, 2011, retrieved on June 15, 2011. http://9to5mac.com/2011/06/15/awesome-use-of-an-ipad-and-the-parrot-ar-drone/.

[11] Faigl, J., Krajnık, T., Vonasek, V., and Preucil, L. (2010) "Surveillance planning with localization uncertainty for mobile robots." 3rd Israeli Conference on Robotic.

[12] Ng, W.S., and Sharlin, E. (2011) "Collocated interaction with flying robots." Technical Report 2011-998-10, Department of Computer Science, University of Calgary, Calgary, Canada (2011).

[13] Higuchi, K., Shimada, T., and Rekimoto, J. (2011) "Flying sports assistant: external visual imagery representation for sports training." 2nd Augmented Human International Conference, New York, NY, USA, ACM 7:1–7:4.

[14] DiCesare, A., Gustafson, K., & Lindenfelzer, P. (2009). Design Optimization of a Quad-Rotor Capable of Autonomous Flight.

[15] J. Fraden, *Handbook of Modern Sensors: Physics, Designs, and Applications.* Springer Science+Business Media, New York 3rd Ed., 2004.

[16] E. Johnson. AE 4580. Class Lecture, Topics: "Inertial Navigation System" School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA, Mar. 9, 2008.