DESIGN OF AN AUTONOMOUS SURVEILLANCE QUAD COPTER

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ABSTRACT

This paper describes the design and construction of a quad-copter with surveillance capabilities. The system incorporates several subsystems working in unison for communication and control. All of the maneuvering and stability management is controlled autonomously onboard of the quad copter by flight controller APM 2.7. Furthermore, it is used for autonomous flight from takeoff to landing. This device could be used to speedily gather information about an area from a stance point that would normally be inaccessible to human beings. The Mobiousmini action camera 1080P mounted on the quad copter captures live video of an environment and the data is serially sent back to a monitoring device where it can be observed or stored for further processing. GPS module of N6N is used for further controlled navigation. 3D-Model of the quad-copter was generated on an open source system design tool Blender 2.76 before implementation on hardware.

Keywords: Quad-copter, APM 2.7, Autonomous flight, Mobious mini camera, 3D-model, GPS module

1) INTRODUCTION

A helicopter is a multi-rotor, vertical takeoff and landing vehicle that has rapidly spinning rotors that push air downward and hence generate an upward lift to keep itself aloft. Quad-copter is a type of helicopter with four equally spaced rotors that can rotate independently. All the motors are of same capacity and have to share one fourth of the total weight of the system. By controlling the speed of these rotors, we can obtain the six degree of freedom as show in fig1 (Kader et al., 2014).
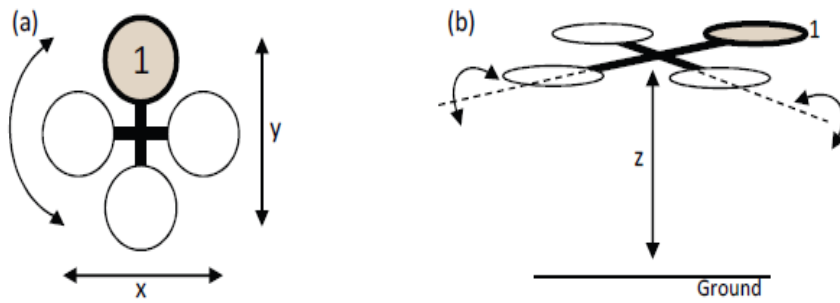
Figure 1: Degree of Freedom of a Quadcopter (Leong et al., 2012)

Two of the opposite rotors spin in clockwise direction and the other two rotate in anticlockwise direction to cancel the torque generated by the first two rotors. So the overall torque of the system cancels out for stable hovering.

Maneuvering refers to controlling the yaw, roll, pitch and altitude of the copter by varying the relative thrusts of each rotor (Huang et al., 2009). Increasing or decreasing the speeds of all the motors by the same amount leads to the increase or decrease in the altitude of quad-copter. To yaw, the speed of the two opposite rotors is turned up while taking away the speed of the other two rotors by such an amount that the upward thrust of the quad-copter remains same but the torque on one side exceeds the countering torque. To roll or pitch, the speed of one propeller is increased and the speed of its alternate propeller in decreased by the same amount while keeping the speed of the rest constant (Batmaz et al., 2013). This increases the vertical thrust on one side of the horizontal plane of quad-copter and hence the system moves forward.
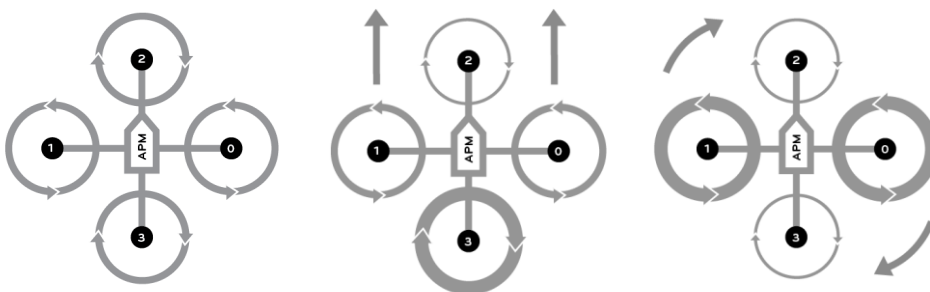

Figure 2: Movement Controls (a) Yaw (b) Roll and Pitch (c) Hovering (Leong et al., 2012)

Quad-copters provide many advantages and ease when used for the surveillance, reconnaissance, and inspection in complex and dangerous environments where involvement of human beings is insecure and unsafe (Ross et al., 2013). Quad-copters also provide the advantages of flying at the required altitude, indoor and in obstacle prone environment.

Quad-copters are encountered in an increasing number of civilian and military applications like inspecting and exploring complex environments (disaster areas, battle fields, etc.). Autonomous guidance, navigation and control (GNC) are required to achieve these missions without direct or continuous human control. Guidance and navigation systems were originally developed for rockets (Gupte et al., 2012). The systems entered more widespread use with the advent of spacecraft, guided missiles, and Quad-copters. GNC consists of three essential parts:

Guidance system_ which steers the Quad-copter toward a desired state (location, target, etc.)
Navigation system_ which tracks current location of the Quad-copter and estimates its state.
Control loop_ (autopilot) Generation of actuator signals after accepting guidance commands and navigation data to produce a stable flight. (Nagarjuna and Suresh, 2015).

Guidance system of the autonomous Quad-copter consists of the flight controller of the quad-copter. Depending upon the position of the quad-copter is decides about the path. It takes the position of the quad-copter from the navigation system and it also makes sure that the system is safe from obstacles and lands smoothly. Navigation system of the quad-copter is used to decide its exact position with respect to the external environment. For navigation many technologies and sensors are being used now a day. A lot of algorithms have been developed for autonomous navigation (Garcia et al., 2015, Krajník et al., 2012).

2) BACKGROUND

Quad-copter finds enormous applications in the industries like defense and rescue. The Quad-copters can be used to monitor hazardous area that human cannot reach. So, for situations where human observation is unsafe, a Quad-copter takes the stage. Quad-copters are already being used in several military and civilian domains, including surveillance operations, weather observation and causality areas and for inspection purposes.

The project started with the study of algorithms which were designed for the autonomous control of Quad-copters while achieving a stable and controlled fight. New techniques and design strategies were appended to the existing methods and were implemented on the hardware.

These are some applications behind the selection of quad copter as a project.

2.1) Applications

Quad-copter can potentially be used to save lives or prevent harm to others. Quad-copter can monitor real time environment and consequently take action upon some unknown event like gunshot detection and tracking of person who caused it. In natural disasters the inspection of the area under consideration is crucial for the field teams to be effective in their missions. Whether it is a search for injured trekkers in a cliff or looking for victims at night using thermal camera, this all can be done using a surveillance Quad-copter, without endangering search teams. In a forest-fire scenario it is often difficult to have an updated and global awareness of various elements involved. The small Quad copter UA Vision is compact and easy to operate, and can easily be launched from a command-and-control vehicle (Vedder et al., 2015). In a few minutes, the field teams can start to receive images and footage from the Quad-copter UA Vision, and develop a better up-to-date situational awareness of the operations theatre. Even in urban building fires, the Quad copter UA Vision enables a close-up visual inspection of windows, doors and openings in different floors to assess safety conditions and risk calculation to plan fire-fighting intervention. The Quad copter UA Vision onboard computer takes care of making the aircraft stable, ensuring an easy-to-use operation. This allows the fire-fighters to gathering information of the disastrous area to reduce

the risk and increase the effectiveness of the missions in the field. (Ross et al., 2013).

Entering an unknown and dangerous environment is often a task assigned to law enforcement agencies. Improved situation awareness and prior knowledge of the vicinity, before exposing the team to the area can reduce the potential risk of injuries (Haque et al., 2014, Vedder et al., 2015).

Insurance investigators and law enforcement agencies can collect the photographic evidence of the scenarios to get the better perspective of the area under investigation. Panoramic view or spectrum cameras can be used to make image based measurements and can improve the efficiency of investigators in charge.
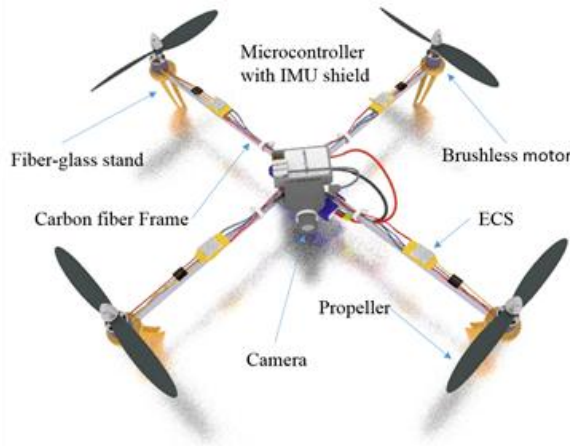
*Figure 3: 3D Model of the proposed quad-copter system*

To manage spill hazards the most important task is to gather accurate data in the minimum amount of time. In this type of scenarios, initial response teams can use the Quad-copter UA Vision to collect geo-tagged crucial evidence to understand the source and causes of the disaster (Lee and Kwak, 2014, Ma'sum et al., 2013, Zou and Tseng, 2012).

3) MECHANICAL MODEL

Before implementing the quad-copter on hardware, the 3D model of the system was designed on an open source mechanical design tool (Blender 2.76). The generated 3D- Model is displayed in figure 3.

3.1) Frame

Frame is the structure that holds together all the electrical and mechanical components. Frame was chosen as to provide quad-copter with the required strength without adding too much weight overhead to the system. Two hollow carbon-fiber rods were used as a base and were mounted together using a specially designed aluminum mounting that formed a cross-shaped frame. Motor-to-motor distance was chosen to be 50cm. The resultant frame was sturdy enough to resist the vibrations caused by the motors and was light enough to be easily lifted above the ground. A fiberglass landing gear was designed, that was able to withstand the landing pressure (Benavidez et al., 2014).
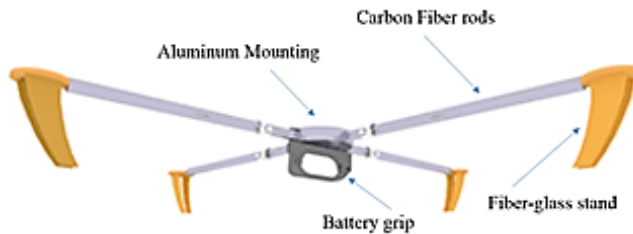
Figure 4: Frame of quad-copter

3.2) Propellers

Propellers are available with different diameters and pitches. Increasing both the diameter and the pitch generated more lift but also consumed more power. Our goal was to choose a propeller that can provide us with the perfect blend of upward thrust, power consumption and maneuverability with high RPM motors.

The propellers that we narrowed down to, were EPP1045 propellers with 10 inches diameter and 4.5 pitch. These propellers were made up of high quality unbreakable plastic that made them rough bust and light weight at the same time.
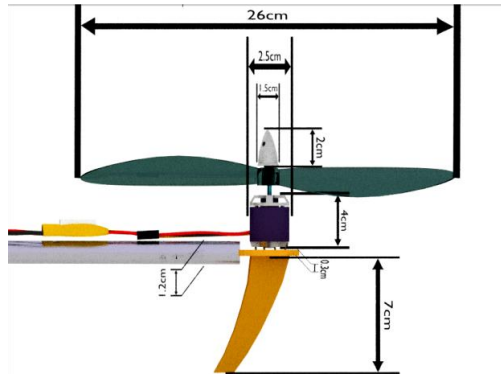
Figure 5: Propellers details used in quad-copter

4) ELECTRICAL COMPONENTS

4.1) Flight Controller

A flight controller acts as a brain of the system. It receives inputs from sensors and in response, controls the speed of the motors. The flight controller that we chose was an open source Arduino based microcontroller AMP 2.7 that was aided with an Inertial Measuring Unit (IMU shield) to compliment it with required sensors. Onboard sensors included a gyroscope, a barometer, a compass and an accelerometer. Data from these sensors allow our microprocessor to calculate changes in the motor speeds which makes sure that the quad-copter maintains a controlled maneuver and a stabilized hover.

4.2) Motors

Brushless motors were used as they are able to provide us with much higher RPM while keeping the power consumption low. This type of motor consists of outer runner which has shells of small magnets on inner periphery. The outer runner spins around precision bearings and there is a winding tightly wound on laminated iron core. Propellers are installed on the shaft of the motor using nuts. Brushless motors have different specifications like voltage, rated current and kV rating. KV rating of motor is responsible for the velocity constant of the motor in RPM by which motor rotates providing 1 Volt on no load condition. Short shaft version NTM 28-30S 800KV brushless motors were used. Each of them added a weight cost of 70g to the system.

4.3) RC Transmitter and Receiver

For manual control of quad copter, a RC transmitter and receiver is used. It has a high frequency digital communication link with receiver. Receiver is installed on the quadcopter which receives the user reference signal and provides PWM output signal. Quad copter attains the orientation according reference angles (roll, pitch and yaw) provided by the user. In this project 6 channel 2.4 GHz RC transmitter and receiver are used.

4.4) Battery

The most important factors that decided the battery were high current rating and less weight. Lithium Polymer (LiPo) battery was chosen, as it provided us with the best power to weight ratio. A 4000mA Lipo battery was used that provided us with the flight time of 7min with the weight cost of 430g.

4.5) Electronic Speed Controllers (ESC)

Brushless motors usually come as multi-phased motors, so a direct supply of DC power is not able to turn these motors. To convert a DC signal into a frequency-phase controlled signal we use an ESC. Each of the ESC is controlled independently using a pulse position modulated (PPM) signal, generated by the microcontroller.

The factors that contributed most in choosing the ESC were the amount of tolerable source current and compatibility with our microcontroller. Afro ESC 30A 27g was chosen, as it allows the maximum of 30A source current which was in a safe range of what our motors can consume and was compatible with an Arduino based platform.

4.6) GPS Module

GPS module interacts with the satellite and retrieves the accurate information of the position and speed of the vehicle. This data allows the drone to fly autonomously by following the points given to it using a geotagging software. Ublox LEA 6h GPS Module was used due to its compact size and accurate information.

4.7) 3-DR Power Module

A Power Module is used to power up the microcontroller, a RC receiver and other microcontroller accessories. 6-pos DF13 cable plugs directly to microcontrollers 'PM' connector.

4.8) Proximity Sensors

Ultrasonic Range sensors are mounted on the four arms of the quad-copter. When these sensors detect an obstacle in its vicinity the microcontroller gives out rebound instructions. Rebound is generated using the motors hence avoiding any collision.

5) ELECTRONIC CIRCUIT FLOW DIAGRAM

Electronic circuit flow diagram of the system is displayed in Figure 6. The figure depicts the integration of different subsystems to form one complete product.
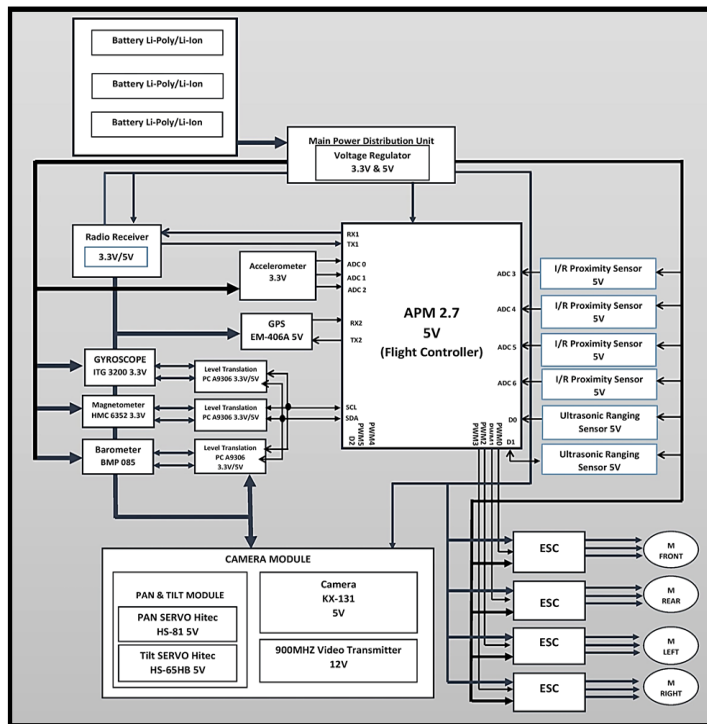

Figure 6: Electronic Circuit flow diagram of the system working in quad-copter

6) DATA CAPTURE AND TRANSMISSION

Surveillance capabilities were provided to the quad-copter. For that a camera was mounted on the copter which was able to capture a smooth video data and a wireless telemetric system transmitted that data back to monitoring device where the data could be observed, processed or stored. Following is the brief detail of the individual components that contributed towards the surveillance mechanism.

6.1) Camera

The camera that was deployed on the system was a Mobiousmini JPEG color camera. This camera employs a transistor- transistor-level (TTL) logic signal. The camera operates on 5Volts power supply and drew 100mA current. The main reason behind choosing this camera was its ability to integrate video data over a serial connection. We were able to obtain 29 frames per second at 1280x720 pixels which was sufficient to perform surveillance.

6.2) Law Mate Wireless AV-Trans Receiver

For the wireless transmission of analog audio and video data. We opted a 2.4Gz 8CH trans-receiver. Transmitter module transmits 500mW of power that can range more than 3000m in open area. It has a built-in frequency phase locked loop (PLL) technology to prevent frequency drifting. The transmitter works on 6.5 to 15 volts and consumes 300mA with the weight of 35g. Receiver is attached to the laptop to receive A/V data which can be observed or stored.

6.3) Telemetry Radio

Telemetry radio is an open source radio platform that can communicate up to three kilometers with the use of a patch antenna. It works on 915MHz. One module was attached to the quad-copter and the other is connected with the monitoring device. MAVlink based ground station software can be used for planning the autonomous flight and directing the copter using the giving waypoints.

6.4) Weight Chart

Following chart shows the weight cost of different components of the system.

Table 1: Weight Chart of Components of Quad copter

COMPONETS	WEIGHT
Brushless motors	70 x 4 = **280g**
Flight Controller	**32g**
Electronic Speed Controller(with heat sink)	26.5 x 4 = **106g**
Li-Po Battery	**430g**
GPS and power module	**25g**
Receiver 2.4Ghz	**9g**
FPY camera	**38.5g**
Propellers	10 x 4 = **40g**
Frame	**471g**
TOTAL	**1420.5g**

7) EXPERIMENTAL RESULTS

The resultant quad-copter was able to takeoff autonomously, complete the surveillance and land safely at the point of takeoff. The user was able to plan the complete surveillance mission using the geotagging MAVLink ground based mission planner after which the quad-copter completed the surveillance successfully. The captured data was successfully communicated back to the monitoring device. Live data from GPS module enabled the user to observe the current position of the quad-copter during the mission.

There were some issues while doing this project such as minimum recommended fence radius should be 30m. This fence requires GPS to work well. RTL should be working on vehicle. When fence is enabled, GPS should be locked before arming the vehicle. When fence and GPS fail-safe is enabled, the vehicle will switch to land safely. After solving these issues quad copter was finally able to fly. It was also able to maintain its stability.

Figure 7: Successful Development of quad-copter

8) CONCLUSION

The goal of this project was to design and construct an autonomous quad-copter with surveillance capabilities. The system contains various subsystems working simultaneously for communication and control purpose. With the help of four brushless motors NTM 28-30S 800KV, a stable Quad-copter was made. The quad copter used OrangeRx T-SIX 2.4GHz transmitter for positional feedback and sent commands to the Controller. A camera was mounted upon the quad copter which was able to communicate the video back to the monitoring device. An Ublox 6h GPS Module was also placed on quad copter for navigation. This device could be used to gather information quickly about an area from the point that would normally be inaccessible or hazardous to human beings.

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