IFERP

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)

Vol 9, Issue 5, May 2022

A Systematic Design of an Unmanned Aerial Vehicle for Surveillance Applications

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Abstract— In the past few years, the demand for Unmanned Aerial Vehicles, more commonly known as drones, has increased exponentially. This is mostly because they have huge applications in various areas like mapping, surveillance, payload delivery, aerial photography, wildlife surveillance, etc. VTOL, or Vertical Takeoff and Landing is a concept in which an aircraft or a UAV takes off and lands vertically. This concept has its own advantages over traditional fixed wing takeoff and landing systems. It does not require a large strip of land for takeoff, and the required lift can be generated from the thrust produced by the motors. It also enables a better and smoother landing than conventional fixed-wing systems. This paper presents a design for a quadcopter UAV system which can be used for surveillance in various disciplines. A unique concept of a hybrid frame has been introduced. This largely improves the stability and reduces vibrations to a great extent. Surveillance is carried out using Python, which detects objects using OpenCV and the YOLO algorithm.

Keywords — VTOL, UAV, surveillance, Python, OpenCV, YOLO

I. INTRODUCTION

With improvements in technology, using it to our benefit without harming natural ecosystem is of utmost importance in today’s world. Implementation of UAVs for various applications which can save human effort is a good pathway to achieving sustainable technological advancement. The finished build of our UAV can be used for surveillance for home and commercial security as well as defense applications. The camera attached to the UAV detects motion and objects around it and transmits the live feed directly to the user for interpretation. This feed can enable the user to take quick action according to the received data. The concept of VTOL, or Vertical Takeoff and Landing has been used to minimize the requirements for a large strip of land for takeoff and landing. The concept of a hybrid frame also has been introduced to minimize vibrations and maximize stability.

II. LITERATURE REVIEW

Sai Krishna A., B. Avinash and Vamsi Krishna C. proposed a design of a hybrid UAV which could combine the hover capability of helicopters and the high speed of fixed wing aircrafts. They systematically designed the aircraft, carried out various CFD simulations to achieve a successful flight.[2]

Rajath Shetty, Pavan Kalyan V, Madhu Pujar, Peddi Reddy Omkaram Reddy published a paper in which the authors designed a fixed wing UAV which could be compatible in both air and underwater environments. They efficiently integrated both aerodynamics and hydrodynamics to achieve a highly stable UAV. [3]

Muhammed Hasnain Kabir Nayeem, Md. Thariqul Islam Pranto, Raad Shahmat Haque , Taimum Al-Nafis published a paper in which they designed an unmanned aerial vehicle for pipeline inspection for various oil and gas companies through airborne laser scanning. [4]

Kyuho Lee proposed a thesis in which the author discussed a systematic design approach for a UAV which could be used for Wildlife surveillance. They also discussed various surveillance techniques like Oscillating path, random path, etc. [5]

A team from California State University undertook a project in which they designed a solar-powered autonomous aircraft for aerial observation. They used a Kestrel Autopilot system in their project to successfully implement autonomous flight.[6]

Seungwoo Lee published a paper in which they designed a UAV for radiation surveillance, i.e. to detect radiation and prevent radiation based accidents. They also integrated an onboard radiation detection payload system with the UAV. They also demonstrated the use of TCP/IP protocol for communication with the UAV.[7]

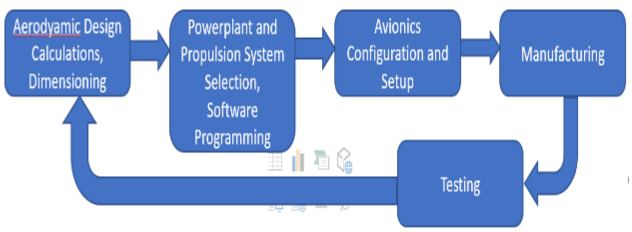
ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)

Vol 9, Issue 5, May 2022

III. METHODOLOGY

A. Workflow



B. Modules

1. Aerodynamics and Propulsion

This module includes powerplant selection, dimensioning, stability analysis and calculations. As the first step, the weight of the UAV was estimated. Taking this estimate into consideration, BLDC motors rated 1000Kv, a 30A ESC and propellers rated 10x4.5 were selected as the propulsion system. Various forces and moments were calculated to ensure the accurate placement of various components to ensure maximum stability

Tools and Components required –

- 4 1000Kv BLDC motors
- 4 30A Electronic Speed Controllers
- 4 10x4.5 propellers
- 2 3S 2200 mAh LiPo Batteries
- Power Distribution Board

2. Avionics

The configurations of the various electronics required to stream the video feed and the setup and operation of the flight controller module are the major parts of this module. The APM 2.8 flight controller board was used as the primary flight controller module. The FlySky FSI6 Transmitter-Receiver were used as the control inputs. The receiver was connected to the input pins of the APM 2.8 board and the output pins are directly connected to the ESCs. The video feed can be transmitted using the TS832 transmitter and the Skydroid Receiver can be connected to the laptop to receive the transmitted video feed.

Tools and Components required –

- TS832 Transmitter
- SkyDroid Receiver
- Telemetry Module
- Arduino UNO
- APM 2.8
- GPS Module
- LEDs

LEDs are mounted on the frame to enable the UAV for night flight.

3. Software

This module consisted of the core programming with could detect and recognize various objects. Python was used as the primary programming language due to its easy usability and presence of multiple support libraries. The YOLO algorithm was used for object detection. Instead of selecting the most intriguing section of an image, the YOLO method predicts classes and bounding boxes for the entire image in a single run of the algorithm. OpenCV is used as computer vision library to access webcam and to display rectangular boxes and accuracy of detected objects.

Libraries required –

- Tensorflow
- Mediapipe
- OpenCV

4. Manufacturing

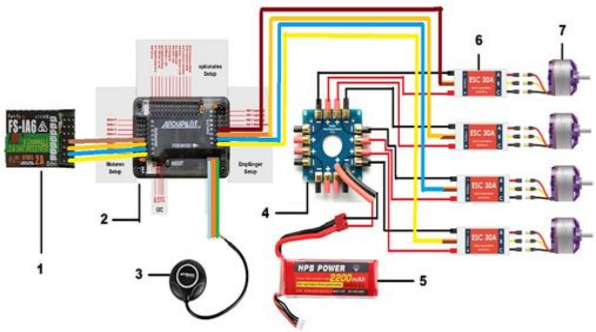
This module consisted of the actual manufacturing of the UAV after all specifications were obtained. This included material research, structural analysis and stability analysis.

Aluminium rods were used to build the frame of the quadcopter because of their light weight.

Tools and Components required –

- Aluminium Rods
- Hacksaw
- Acrylic Sheets

C. Avionics and Propulsion System



D. Design Calculations

<u>Estimated weight of drone – 2kgs</u>. So, the total thrust produced by the motors should be >=2kg or 20N

<u>Dimensions – 35cmx35cm</u>

Dynamic Thrust calculations -

$$F = 4.329399 * 10^{-8} * RPM * \left(\frac{d^{3.5}}{\sqrt{pitch}}\right) * (4.23333 * 10^{-4} * RPM * pitch - V_O)$$

<u>Propeller Configurations -10x4.5</u>

<u>Motor Kv rating = 1100Kv</u>

Putting the values in the equation, we get the thrust produced by 1 motor as 17.94N or 1.794kg.

ISSN (Online) 2395-2717
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Vol 9, Issue 5, May 2022

So, 4 motors would produce 71.76N or 7.176kg of thrust at 100% throttle. So, the thrust to weight ratio becomes approximately 3.5, which is ideal.

- At 75% throttle, the thrust per motor becomes 10.31N or 1.031kg. For all 4 motors, the total thrust produced would be 41.24N or 4.124kg.
- At 50% throttle, the thrust per motor becomes 4.58N or 0.458kg. All 4 motors would produce 1.832kg of thrust.
- At 25% throttle, the thrust per motor becomes 1.14N or 0.114kg. All 4 motors would produce 0.456kg of thrust.

- MOMENTS

The rotation of the drone about the 3 axes can be achieved by causing imbalance in lift forces, which in turn causes imbalance in lift a weight moment, which further causes the drone to either yaw, pitch or roll.

Pitching moment can be caused by causing imbalance between the front and rear pairs of motors. If the front motors are operated at 25% throttle, they will produce 0.228kg of thrust combined. Similarly, the rear motors operated at 50% throttle would produce 0.916kg of thrust combined. This imbalance in lift would cause a net upward moment of 0.229Nm for the rear motors and a net downward moment of 0.057Nm for the forward motors. This will cause the drone to pitch forward.

Similarly, other rotations like yaw and roll can be achieved by causing lift imbalance in the diagonal and side motors respectively.

- HOVERING

Hovering is a special scenario when the drone hovers, i.e. it neither descends not ascends. This can only be achieved when L=mg, or lift=weight.

In this case, the lift should be exactly equal to the weight of the drone, or 20N. So, the thrust produced per motor must be exactly 5N.

Putting the required values in the above formula, we get required RPM as 6377. So, at approximately 52% throttle, the drone would hover.

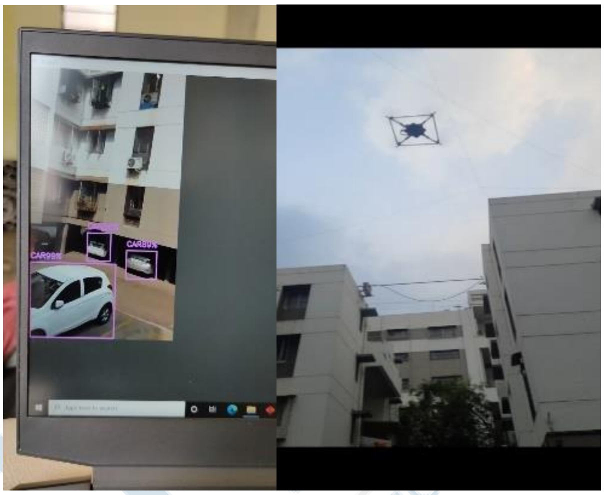
IV. RESULTS AND DISCUSSIONS

A total of 5 test flights were conducted during the testing phase. During the first flight the drone did fly well with great stability but while landing it crashed and major damaged was received to the base plane on which all the were electronics rested upon. Analyzing the video recording a number of times, The design of the landing surface was changed and designed it in a way so that it has a large surface area which will help in minimizing the impact in case of crash or hard landing.

In second test flight, the drone was crashed again. This time one of the propellers came out during the flight, which flipped the drone causing it to lose balance and crash. No major damage taken place as the drone was flying at a low altitude

The third, fourth and fifth test flights all were successful and were according standards. All objectives were achieved.

The Python script for object detection also ran error-free with near-perfect accuracy.



V. CONCLUSION

This paper presents a systematic design approach to design an Unmanned aerial vehicle, more specifically a quadcopter which can be used for short range surveillance applications. It successfully detects the various objects around it with the help of a Python script. However, the proposed system can only work efficiently for short-range surveillance like a housing society or a small commercial complex. For long range applications, more sophisticated circuitry would need to be integrated.

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