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Design and Modelling of Autonomous Quad Copter

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***Abstract*— With an objective to ensure safety of the operators of the vehicles used in dangerous locations, there has been a widespread deployment of unmanned aerial vehicles by the military. The same ranging from the size of 2 feet to a meter can put to varied uses in the military operations as well as deployment in the industrial and commercial functions. The goal of this work was to design and model a quad-copter that is proficient in self-sustained flight through wireless communications along with making use of a microcontroller, not to forget to make the vehicle autonomous. Flight Controller relies on software that enables the users to identify waypoints on a map to direct quad-copter fly to the said locations. They then carry out the required functions like landing or gaining altitude.**

***Keywords*— UAV, GPS, Electronic speed control, Quad-copter, Propellers, APM control board**

I. Introduction

Military use of UAVs can be traced backed to the mid-90s with the conception of Global Hawk and Predator. Initially, they were huge aircrafts with fixed wings spanning to 50-100 foot with payloads comprising of radar, cameras, and missile systems and not to forget laser designators. With the advent of the said aircrafts, there was a reduction in the harm caused to the pilots. Added to it was the advantage of being able to stay in the target area for a longer time. Despite their advantages, there were issues with regards to their size and expense involved. This lead to an exploration of the feasibility of smaller UAVs that would serve the same purpose in a better way when put to military use. Consequently, good amount of research started in this direction in lines of bio-inspired designs. Some of the designs were those that were modelled in line with insects and birds. But the said micro-UAVs were not very practical to be put to use owing to their minute sizes and the fact that appropriate technology that would accomplish the said objective was also not available. [17].

Our research interest centred around vehicles with their size spanning from 1 foot to 1 meter. Further the scope of our research was to establish whether the said vehicles would cater to the commercial and industrial needs along with serving military purposes.

Fig.1: Quad copter

II. Designing of Proposed Hardware System

Coming to the Quad-Copter, it is a small hover of very little weight that can be controlled through a wireless system. A flying robotic mechanism that can be operated with its four fixed rotators, Quad copter is a hover that can enable lift with its rotators in the absence of fixed wings. The rotators contributing to the thrust with the torque being the centre of the rotation along with drag force being opposite to the direction of flight.

What is noticeable is the fact that there is the lack of similarity in the propellers. They have been categorised into two pairs, pushers and puller blades working in contra rotation. This leads to the net torque being null, provided the propellers have the same angular velocity as they turn. This will ensure that around the centre of gravity, the aircraft stays still. Similarly, due to the variation in the rotator speed which is done for the resultant thrust and torque, quad copter motion is enabled. The orientation of the aircraft is defined in three dimensions- yaw angles, pitch and roll.

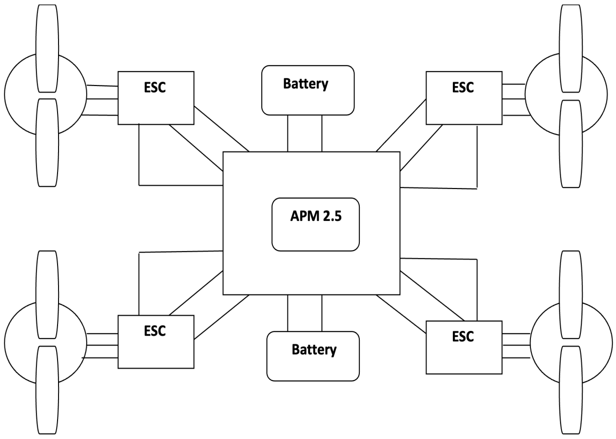

Fig.2: Quad copter Block diagram

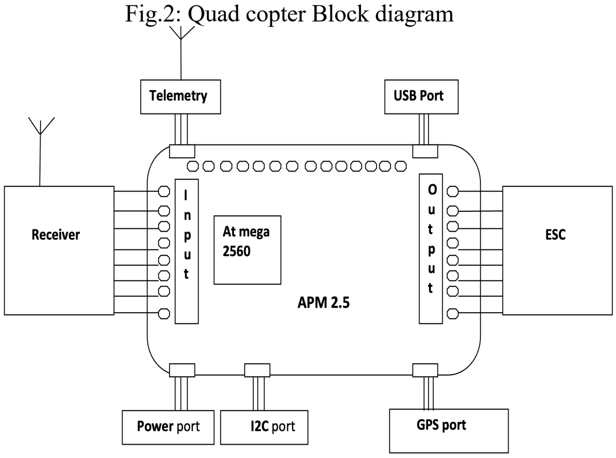

Fig.3: APM 2.5 Controller design

The same happens to be quite useful given the factors that attribute to its aircraft control thus facilitating its pitch, roll or yaw. The pitch angle exhibits changes depending upon varying propellers (1 and 3) speeds thus contributing to backward and forward movements. When the same is repeated for 2^{nd} and 4^{th} propeller, there would be a roll angle change with lateral translation. A mismatch in the aerodynamic torques induces Yaw.

One of the recent Arduino enabled multi copter plat form which is open source is APM. The objective eof this project is to facilitate a multitude of different set of functionalities ranging from stabilized manual flight across the automatic waypoint visiting by making use of GPS. The controls used for Ardu Copter is Ardu Pilot Mega 2.5 which provides compatibility features like Arduino Compatible, 3-axis gyro, digital compass, accelerometer, barometric pressure sensor, magnetometer, 4 MB data flash chip to name a few.

III. Hardware

A. *Motors:*

Motors categorized as Brushless DC electric motors run on dc Voltage along the normal Ac supply. On the other hand, alternating-current motor performs at a speed which is a multiple of the supply frequency. The conventional DC motor comprises of permanent magnets which are stationery, and hence called stators on the either side of the spinning armature. The rotating armature known as the rotor comprises of electromagnet which when run on electricity, produces magnetic field which causes attraction and repulsion of the stator magnets in the armature leading to a spinning of 180 degrees. The evolution of cost effective computers and the transistors that are power enabled, helped in doing away with brushes and hence come the brushless DC motors which have permanent magnets on the rotor.

Such motors result in generation of more torque due to the slow spin. The greater torque when used in Quad copters help in attaining balance due to the varying revolutions of the motor. It can be understood as the speed of the propellers being determined by the torque. The higher is the torque the greater is the speed.

B. *Electronic Speed Controller:*

We can understand the electronic speed control (ESC) as an electronic circuit that is intended to change the speed of the electric motor along with its direction by acting as a dynamic brake. They are more commonly used with radio controlled models that are powered electrically. On the contrary, brushless motors are known for providing a low voltage energy in a three phase electric power.

Coming to the recent deployment, there is a use of battery eliminator circuit (or BEC) to adjust receiver voltage thus eliminating the need for receiver batteries. BECs can be voltage regulators that are either linear or switched. DC ESCs on the other hand are PWM controllers. The ESC generally accepts a nominal 50 Hz PWM servo input signal whose pulse width varies from 1 Ms to 2 Ms. Upon providing 1 ms width pulse at 50 Hz, the DC motor attached is turned off. In case of 1.5 ms pulse-width input signal there is a 50% duty cycle output signal which moves the motor half of the speed. With the input signal being 2.0 ms, the motor performs at full speed, thanks to 100% duty cycle output.

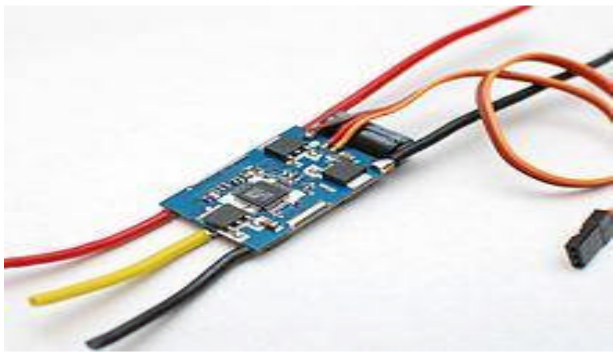

Fig.4: A generic ESC module rated at 35 Amps with an integrated BEC

C. *Propellers:*

Aircraft propellers, which are otherwise called the airscrews are responsible for conversion of rotary motion which is derived from piston, turbo or electric engines, to result in propulsive force. They can be differentiated based on fixed or variable pitch. The evolution of the aircraft propellers can be traced backed when they were hand carved using solid wood. Then there was onset of metal propellers with the recent ones being those designed using technologically enabled composite materials. Using piston engine's crankshaft through reduction unit helps in the attaching the propeller. Though complex gearing is not required for light aircraft engines, the same is called for in case of large engines and the ones using turboprop.

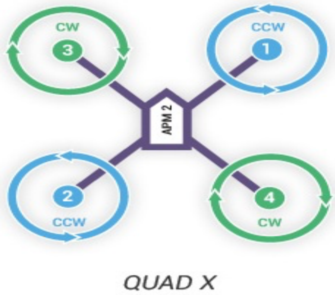

Fig.5: Rotation of propellers

Counter Rotating Propellers:

The twin and multi-engine aircrafts that are propeller driven often make use of counter-rotating propellers. The ones that are used in wing-mounted engines move in the opposite directions as against each other. The propellers in the twin engine aircrafts usually spin clockwise whereas those which are counter rotating spin clockwise in case of left engine and anti-clock wise in case of right engine. The benefit of having counter-rotating propellers is to bring about a judicious balance as far as the effect of the torque and p-factor is concerned thus doing away with the issues involved in critical engines. They are otherwise known as the "handed" propellers as they exhibit the features of left and right hand instances of each prop.

D. APM 2.5 (Ardu Pilot Mega):

One of the set up friendly and flying friendly multi rotator platform for helicopters is Ardu Copter with its functionalities being over and above preliminary manual controlled RC multi copters available. A comprehensive UAV solution, Ardu Copter provides flight that is both autonomous and remote controlled enabled with the waypoints, telemetry and mission planning, clearly defined. [15] The current work works on a DIY mission planner created using APM

Supports following features:

- High quality auto level and auto altitude control
- Unlimited GPS waypoints.
- Return to launch.
- Automatic takeoff and landing.
- The camera controls that happened to be fully scriptable enable the camera to point at any object on the ground.
- It can be used across the platforms like support windows, mac and Linux by using Graphical mission planner in case of Window and command line interface for other operating systems. Post setting up the Ardu Copter, the ground stations can be selected from among the ground controls that are available in the operating system chosen.
- Given its alignment with the laid down robotics standards in line with Willow Garages Robot Operating System and the MAVLink , it proves to be a state of art aerial robotic in the lines of AI control, android compatibility and multi-UAV swarming.

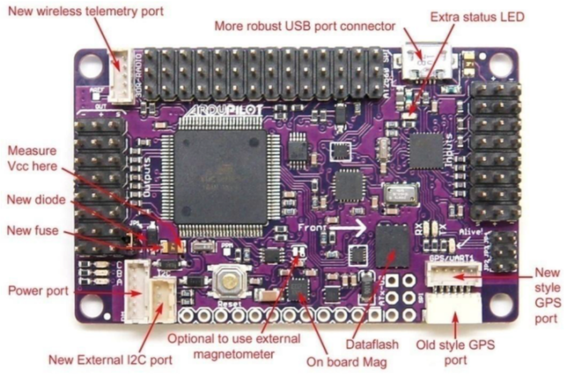

Fig.6: APM 2.5 Board Overview

The RC receiver channels and the ESCs would plug into the inputs and outputs respectively. They can support closer to eight channels out of the box, with the option of expanding them further both in and out. The Power Port Connector that is found in the power module can power the APM 2.5 board. The same can be powered from ESC or any other 5v external source, with the same being of compromised reliability. Alternative power source is enabled by jumpers with JPI pins. In case if the external source is not used the JPI pin jumper needs to be disabled. Incase additional sensors needs to be added, the same can be done by using the nine ports that are found in the top from A0 to A8.

E. GPS:

Among all the GPS modules available in the market, ublox is the most accurate with 2.5m accuracy. The same is integrated with LEA-6H GPS receiver that comprises of 25x25x4mm ceramic patch antenna and UART serial interface not to forget the USB. Navigation during weak signals is enabled by the high performance of ublox LEA-6H. GPS accuracy being very crucial for multi copters, the same is achieved by active circuitry of the ceramic antenna as well as the backup battery.

The google repository comprises of the configuration files for Ardupilot Mega use that are pre-configured. A compatible serial fort is needed for the required power supply as well as for enabling data transfer.

F. Wireless data modules for telemetry and in-flight commands:

3DR Radio and XBEE are the two commonly supported wireless data module by APM 2. The researchers have chosen 3DR Radio for the present study. The same is APM optimized, thus providing with a better range along with cost effective performance as compared to XBEE. Upon the connection of the radio telemetry [2] the Mission Planner port needs to be changed according to the ground radio telemetry module and the setting of the baud rate being 57600. The mission planned needs to be connected to through the MVALink once the APM is powered on. This would help in depicting the live data on the screen.

Fig7: 3DR Radio Telemetry

G. Radio Control:

With RC radio being one of the crucial device, it sends commands to our model. With the ones having four fixed wings, model memory is utilized. The said radios are equipped with LCB enabled menu screens and additional switches for data entry.
The components of RC radio systems comprise of the transmitter which us used for aircraft control by making use of joystick, switches and knobs. The same can be utilized in various modes ranging from normal flying to inverted flying. In case of regular flying, the left stick and the right stick are used for controlling the up and down movement as well as controlling the cyclic left and right movement respectively. The next component is the receiver that is responsible for capturing the radio signals from transmitter and converting them to electrical signals. Yet another element is the transmitter that acts as a channel for identifying as to what can be controlled in the aircraft. This research work makes use of six-channel Fly sky FS-T6 series transmitter for control of the copter, not to forget the battery pack that is used for power supply.

IV. Software System

A. Mission Planner

A free open source software for windows, Mission Planner among other features comprises the feature of Point and click waypoint entry enabled by Google Maps. Other features include Ground station that helps in monitoring missions along with sending in-flight commands. Similarly, there are select missions that can be accessed from drop-down menus. By downloading the mission log files, one can see the sensor output. Further the autopilot performance can also be tested. The Configure APM settings can enable the researcher to observe the output and analyze it.

B. Setting up

Download the Mission Planner from the internet. The prerequisite for the same is the presence of Windows with .net Framework 3.5+. With the Mission Planner which would open the planner window, the right com port and baud rate when selected would enable the communication section. Alternatively, while using USB for connection, Com port windows need to be assigned to APM board and 115299 baud. When the connection is over telemetry, Com port Windows need to be chosen. The same is assigned to telemetry ground adapter and 57600 baud. The Windows Device Manager would provide the necessary information about the ports that are in the machine.
Pressing Connect button would help connecting the USP cable with 20 to 30 seconds lag time to reset the board. Post that the connection is enabled through MAVLink. The parameters are then uploaded from the APM to Mission Planner.

C. Steps

STEP 1: Flash the Firmware into controller (when we are flashing firmware we should connect with USB cable only)

STEP 2: Compass (takes samples for one minute, samples are taken so that apm knows where it is, and from how much distance it is away from motors)

STEP 3: Accel calibration (copter does not know which side is left, which side is right, front, back, sides)
STEP 4: Flying modes (modes pwm is to set in the transmitter, so that when we on off the switch it should shift to different channels
STEP 5: Radio calibration (every time we have to calibrate the radio, whenever the flying modes are changed)
STEP6: Checking flying modes
STEP 7: Test flight (we should tune the pids with trial and error method by flying the copter)
STEP 8: After the tuning is done, it is ready for flying

D. Use of Mission Planner Ground Station

Heads-up Display (HUD) is the ground station view of the corresponding mission planner. Given the APM slider switch being in the flight mode with connection made through the MAVLink, telemetry sent by the APM will be displayed by the screen dials and position.

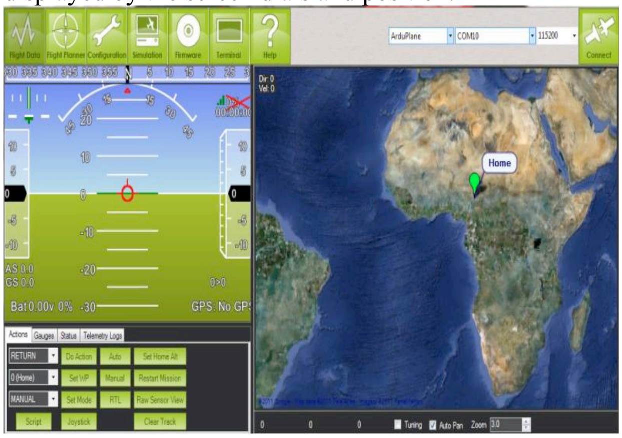

Fig 8: Mission Planner

With the GPS lock, only the current position is available. Other action commands and the required mode changes that one wants to make in the air , can be issued in Mission Planner.

E. Planning of Mission with Waypoints:

The pro UAV has other frequently used functionalities like point and click mission control, which enables go here now functionality, thus not limiting itself to preplanned missions. [7]. Unless and until, it receives further command, the UAV would continue flying there. This is what is referred to as the guided mode, an inbuilt functionality.

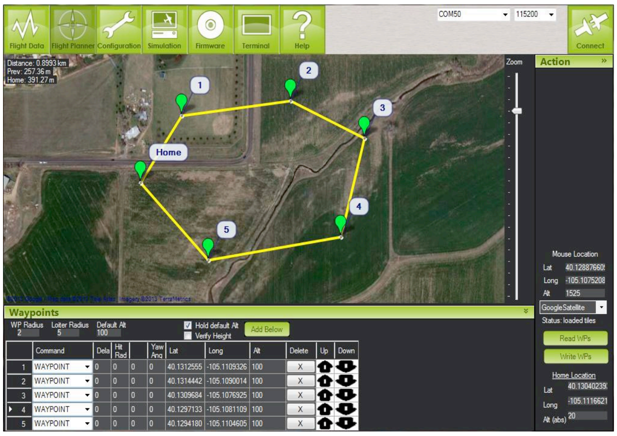

Fig 9: Waypoints

As can be seen in the above screenshot, a mission has been planned starting with a waypoint 1 at 100m, and ending with one the waypoint 5. we can enter waypoints and other commands. One needs to select a command from the dropdown menus as to what needs to be done. The column would then show the corresponding data that is needed by the command. Clicking the map would help us to enter the required latitude and longitude data. As far as altitude is considered, it depends upon the specification of the user as to where they want it to fly.

Set home location (this should be done when we are in field by establishing a connection with the APM and waiting for the GPS lock while the home location link needs to be clicked for setting the home location. Default Altitude is at what altitude copter should fly at the time of waypoints. Waypoint radius is the radius of the waypoint .when copter touch the radius of the waypoint it moves to the next waypoint. In this way it covers all the waypoints which are drawn on the map. Loiter radius is t

The radius at which copter holds at the orbit and fly in that radius. Ardupilot will automatically loiter above home after the last waypoint. If we want Ardupilot to loiter over a specific point, mission scripting is useful. Post achieving our mission, “Write” needs to be selected, upon which the same would reach APM and gets saved in EEPROM. One can save multitude of mission files in the local hard drive. The same can be achieved by selection of “Save WP File”. Alternatively, right clicking the Load WP file would also serve the purpose.

F. Executing the Mission

This comprises of setting up of APM in a way that one extreme would be the Stabilize mode with Auto mode in the other extreme and Loiter mode being in the middle of the three-position mode. First, it´s important that Stabilize Mode is working OK. Set the Mode switch to Stabilize, turn on the transmitter and connect our battery. Wait until the GPS gets a lock. (Blue GPS LED on the APM should be on and solid before arming and taking off. It is even better to wait a bit longer to allow the GPS acquire additional satellites). Start flying in Stabilize mode. It has to be ensured that one can take off with ease and comfort and land safely. Upon finding it tilted, one needs to If we find it tilting, “Level” command which is found in the mission planner needs to be enabled. It is essential that it should remain in the said position at about plus or minus 5 meters in the Loiter mode in an altitude of about 20 meters. When we have finished flying in Loiter mode we go for Auto mode. When we go for this auto mode, mission is activated and copter moves to waypoints which are specified in the graph. After the completion of all waypoints it will fly around home location with the loiter radius. Then it calls for stabilize mode switching before landing. (It is not possible to turn off the motors post landing in the Auto mode or Loiter.

V. Conclusions

From the research done here, it is feasible to design and build a quad copter capable of mission support. Although a working quad copter was built, there is much room for many improvements. First of all, it was made much more stable so that we could let it fly in an open place. We have deployed GPS enabled automatic waypoint visiting instead of manual flight. Commands were sent wirelessly to the copter through the telemetry when it in the autonomous mode. Finally, the copter was made autonomous by setting the waypoints on a map in the software and perform tasks such as landing or gaining altitude.

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