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# DESIGN AND FABRICATION OF AN AUTONOMOUS SURVEILLANCE HEXACOPTER

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***Abstract****- Unmanned Aerial Vehicles are increasingly used for the purpose of surveillance. Many fixed wing Unmanned Aerial Vehicles are designed and used for this purpose and much analysis is performed for such cases. To outweigh the disadvantages of fixed wing Unmanned Aerial Vehicle, rotary wing Unmanned Aerial Vehicle can be used. Again, among the rotary wing Unmanned Aerial Vehicles, hexacopter is an attractive alternative. Hexacopters are more stable than tri-copter and quad-copter. This research work will deal with the design and fabrication of a hexacopter which has some special features like- dual camera, used for fast data transmission as well as High Definition (HD) quality recording; 3D GPS Fix for precise pin-point flying and altitude holding; autonomous flight using autopilot for autonomous surveillance; extra payload carrying capability; auto takeoff and landing using Sonar Sensor.*

**Keywords:** hexacopter, Unmanned Aerial Vehicle (UAV), surveillance, fabrication, autonomous.

## 1. INTRODUCTION

A multirotor is a rotorcraft with more than two rotors. An advantage of multirotor aircraft is the simpler rotor mechanics required for flight control. Unlike single- and double-rotor helicopters, which use complex variable pitch rotors whose pitch varies as the blade rotates for flight stability and control, multirotors often use fixed-pitch blades; control of vehicle motion is achieved by varying the relative speed of each rotor to change the thrust and torque produced by each.

Due to their ease of both construction and control, multirotor aircraft are frequently used in model and radio control aircraft projects in which the names tricopter, quadcopter, hexacopter and octocopter are frequently used to refer to 3-, 4-, 6- and 8-rotor helicopters, respectively.

Unlike quadcopters, Hexacopters have higher speeds and are more power due to the two extra motors included, fly higher in the air than ever before and it reaches higher elevations with ease compared to its counterpart. In addition, by having 6 motors 120 degrees apart, one motor can die while the rest pick up the slack. This means that a pilot will be able to safely land the drone even if one motor is damaged.

The Hexacopter has six rotors arranged in a 'X' shape. The motors are arranged in clock and counter-clockwise manner. This type of counter-rotating rotor-pairs setup will cancel out the rotating force produced by the rotating rotor where the conventional helicopter uses the tail rotor to counter it.

In case of surveillance, now-a-days, irrespective of fixed or rotary wing aircraft, aerial vehicles need a ground control station consisting of a computer for mission planning and overall real-time observation during the flight, and a monitor with video receiver for the broadcast.

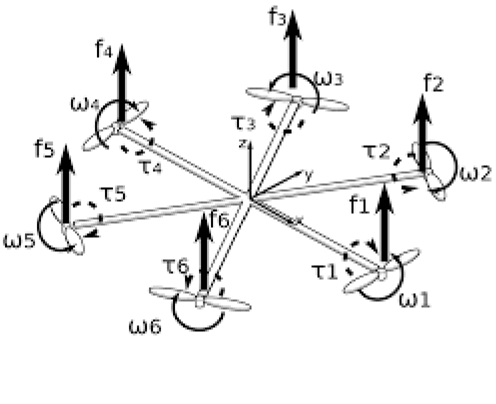


Fig.1: Counter Rotating Motor rotation of Hexacopter

## 2. STRUCTURE SELECTION

The structure was required to be simple, rugged and stable with the capability of longer flight with less drag, weight and higher efficiency. It is evident that long propellers are more efficient than short propellers [1]; as such, to use 6 long propellers, the hexacopter frame had to be big enough. According to the analysis it is seen that from various available on-the-shelf hexacopter frames, 550 sized (diagonal distance 550 mm) frames are more suitable than the others and that sourcing the frame from commercial RC stores would pave the way of gaining higher strength-to-weight ratio for the machine than fabricating a new one with aluminium bars and locally available materials. Thus *HMF S550 F550 Hexacopter Frame* was selected, where the main frame weights 550g with Gimbal hanging rail and landing gears.

Fig.2: HMF S550 F550 Hexacopter Frame

## 3. PROPULSION SYSTEM

As the target was to achieve higher efficiency using long bladed propellers, the motor had to be of low RPM but high torque, i.e. power. Thus the motors chosen were the MT2216 Brushless DC Motor (BLDC) Motor having 850 kv (rpm per volt), direct drive. Weight per motor is 62 grams. In order to achieve a good performance and efficiency, the propeller has to be of a good twist angle, followed by a variable chord design to maintain Boundary layer over the surface of the aerofoil of the blades. Sourcing of such a propeller lead us to find EMAX1045 having all the features to gain a good performance according to the data sheets. The rotors were of 10” diameter CW and CCW counter rotating propeller pair. A 4 cell 5000 mAh 25C rated Lipo battery was used in this case having 74 WH energy. Maximum thrust achieved with this combination was 950g per motor and the current required to generate maximum thrust was 14.5 A.


Fig.3: EMAX1045 propeller AutoCAD schematic (left); MT2216 BLDC Motor with EMAX1045 propeller (right)

## 4. ELECTRONICS

### 4.1 Electric Speed Controller (ESC)

Electric speed controllers are required to vary the RPM of the Brushless DC motors according to the PWM signal pushed through transmitter to the receiver or by the Autopilot system. As the overall flight control is totally dependent on the thrust gained by the motor, which varies with their RPM, so the ESC has to be of the finest categories. Although the current required to generate maximum thrust was 14.5 A, a programmable ZTW 20A Beatles series ESC of 50 Hz was used.

Fig.4: ZTW 20A Beatles ESC

### 4.2 Autopilot System

An autopilot is used to control the trajectory of a vehicle without constant 'hands-on' control by a human operator being required. Although modern UAV autopilot systems are totally autonomous, starting from take-off to land without any input from the pilot.

Various autopilot systems are available now-a-days depending on the size, capability, platform to use, price, accuracy and so on. For this hexa copter, Ardu Pilot 2.5 Autopilot Suite was chosen. Ardu Pilot 2.5 is the most cheap open source autopilot system currently available; as such it would grant everyone the way to develop surveillance UAVs at the lowest cost.

The flight controller was attached to the frame using 4 cubes of vibration dampening foam to reduce the error or false reading of the accelerometer of the ardu pilot. It was placed close to the center of gravity of the vehicle (both horizontally and vertically). Generally the controller should be placed within a few centimeters of the middle of the vehicle and level with the motors.


Fig.5: Ardupilot MEGA 2.5

### 4.3 GPS System

GPS modules generally needs to be positioned outside of the vehicle (in an elevated position if appropriate) with a clear view of the sky, as far as possible from the motors and ESCs, with the arrow facing forward. Distance of the module from DC power wiring and the batteries should be at least 10cm to avoid magnetic interferences with the compass [5].

Ublox NEO 6M High Accuracy GPS Module was used with Ardupilot 2.5. This module permits the GPS to be mounted separately from the flight control module so that it can have the best clear (view) of the sky and allows the compass to be distanced from interfering magnetic fields.

### 4.4 Other Electronics

In addition to the above mentioned electronic devices, the hexa needs some other electronics for proper operation. They are:

(1) Power Module: The 3DR Power Module was used in this case. The power module is a simple way of providing the flight controller with clean power from a LiPo battery as well as current consumption and battery voltage measurements, all through a 6-pos cable. The on-board switching regulator outputs 5.3V and a maximum of 2.25A from up to a 4S LiPo battery.

(2) Telemetry: The machine uses Radio telemetry system which is based on 3DR Radio system, designed as an open source Xbee replacement radio set, offering longer range (approximately one mile) and superior performance. Its operating frequency is 915 MHz and operates through the serial board (for the air) and USB (for the ground) configurations. The system provides a full-duplex link using HopeRF's HM-TRP modules running custom, open source firmware. Interface to the module is via standard 5V-tolerant TTL serial / FTDI USB serial.

Fig.6: 3DR Power Module (left), 915 MHz Telemetry (right)

(3) Transmitter and Receiver: To maintain all the systems, a 9 channel transmitter was needed. The $1^{st}$ four channels are generally used for flight controls, rest are for other operations. In this case, the $5^{th}$ channel was used to switch between flight modes (i.e. manual control, stabilize mode, autonomous mode, Return to Home mode etc.). The $6^{th}$, $7^{th}$ and $8^{th}$ channel is used to control camera gimbal for maintaining camera Pan/Tilt/Yaw from ground as desired.

Fig.7: FlySky TH 9X Transmitter and Receiver

## 4. COMPLETE ASSEMBLY

The Ardupilot 2.5 consists of 8 input and 8 output channels, Telemetry port (Telem), GPS and I2C port, one Power Module port (PM) and several serial ports for optional use.

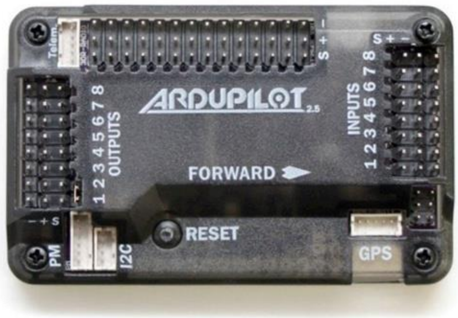


Fig.8: Ardupilot Mega 2.5 connection ports

The inputs from the receiver, outputs to the ESCs, Telemetry, GPS and the Power Module was connected to the Ardupilot accordingly (refer Fig.11).

Connecting the ESCs, i.e. the brushless DC motors to the output ports of the Ardupilot requires a serial to be maintained. According to the ArduPilot 2.5 Hexa-X firmware (which is definitely different from Hexa + configuration), the six motors is to be connected, from output port 1 to 6, in the following manner (Fig. 10). The motor direction of rotation (DoR) was matched according to the prescribed diagram, i.e. the motors were connected to the Ardupilot board in this serial.

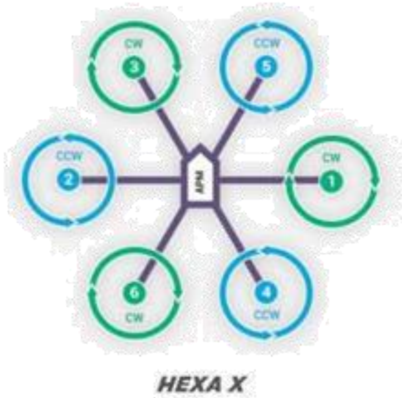


Fig.9: Motor serial of Hexa copter for Ardu pilot 2.5

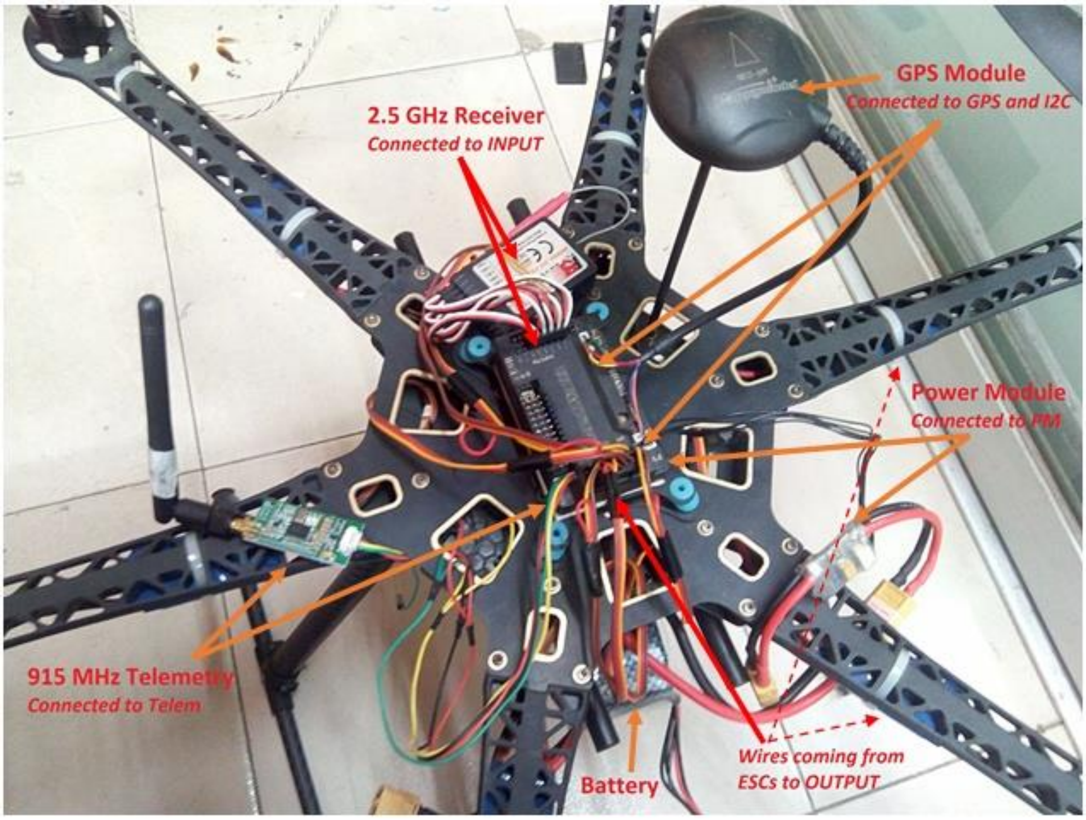


Fig.10: Complete assembly of the *Hexacopter*

## 5. GROUND CONTROL STATION AND INITIAL SETUP

The ground control station consists of a laptop for copter controls and a monitor for video surveillance (as discussed previously). Setup of the laptop for the copter control required some certain steps, respectively:

1. Installing Mission Planner software (Fig.12) on the laptop computer which will be used to install Copter firmware on flight controller and to perform the required calibration and configuration.

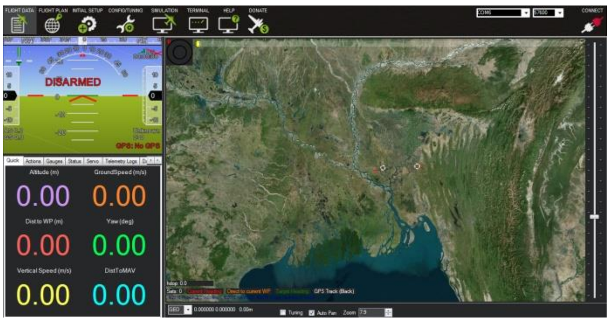


Fig.11: Mission Planner software FLIGHT DATA page for copter attitude display

2. Powering up the transmitter and the hexacopter (without propellers), respectively, for initial setup.
3. Connecting the telemetry device (USB portion) to the computer and loading the latest version of the Hexa-Copter Firmware onto the Arducopter (before connecting the Ardupilot with telemetry by the top-right corner button "connect").

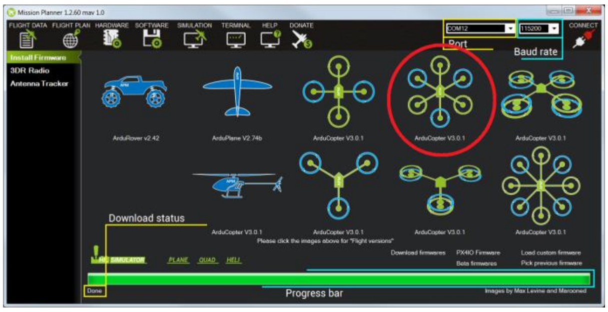


Fig.12: Installing Firmware with Mission Planner software

4. After uploading the firmware, using Mission Planner, mandatory setup were to be done from "Initial Setup" tab, which included, compass and accelerometer calibration, radio control i.e. transmitter calibration, and setting up the desired flight modes as required.
5. Lastly, for the safety of the copter, fail safe option was enabled for contact failure with ground control station. The fail safe option provides the facility of Return to Launch (RTL) facility so that the copter gets back to where it started from and land automatically. The full failsafe parameters installed on the hexacopter is given in Table 1.

Table 1: Failsafe Trigger and Actions

| Trigger Description | Acton |
|---|---|
| Transmitter signal failure (Radio Failsafe) | Return-to-Launch (RTL) |
| Out of telemetry range, <1 sec. (SHORT FAILSAFE) | Circle at current altitude* |
| Out of telemetry range, >20 sec. (LONG FAILSAFE) | Return-to-Launch (RTL)* |
| Low Battery, <15.2 Volts (Battery Failsafe) | Return-to-Launch (RTL) |

** If SHORT FAILSAFE option is selected to cause the aircraft circle, then it will enter CIRCLE mode after 1.5 seconds of failsafe, and then enter RTL if the failsafe condition persists for 20 seconds and will always enter RTL after 20 seconds of failsafe, regardless of the LONG FAILSAFE setting, which can also be set to 'Continue Mission'. In this case, as the SHORT FAILSAFE was selected to CIRCLE, so the hexacopter would never go for LONG FAILSAFE action.*

6. Setting up the combination for arming the copter using a certain combination of the control stick. In this case, the combination of zero throttle-right yaw was used. The stick position is shown in Fig.14

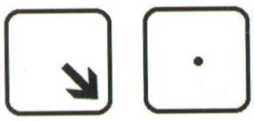

Fig.13: Control Stick position for Arming motors

### 5.1 PID Tunning

A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured Process Variable *(PV)* and a desired Set-Point *(SP)*. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.

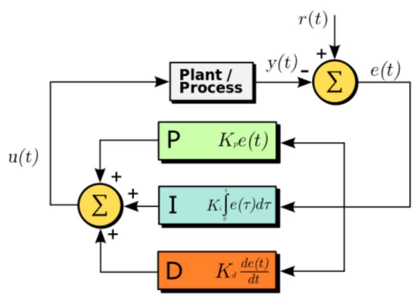


Fig.14: A block diagram of a PID controller in a feedback loop

The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. As to fly autonomous, a proper PID tuning is a must for all sorts of aircraft for eliminating errors in the flight attitude to gain successful operation. The default PID gains in the Ardupilot 2.5 are meant for a wide variety of multirotor frames. Still to get optimal performance, adjusting them was necessary. The PID controls are found on the Mission Planner's Config/Tuning >> Copter Pids screen [3].

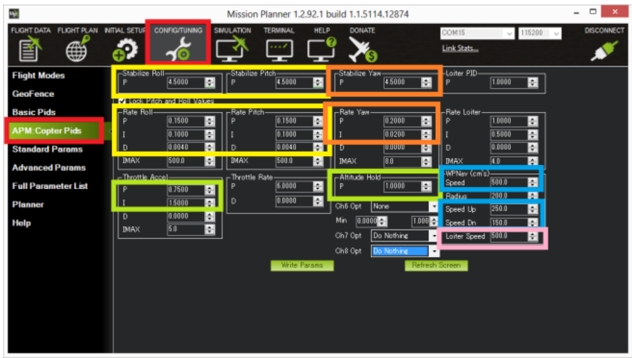

Fig.15: Copter Pids page in Mission Planner

In this case, manual tuning was not needed due to the introduction of AUTO-TUNE in Ardupilot's latest firmware. It attempts to tune the Stabilize P and Rate P and D terms that provide the highest response without significant overshoot. It does this by twitching the copter in the roll and pitch axis which means that the copter needs to be basically flyable in AltHold (Altitude Hold) mode before attempting to use AutoTune [4]. Channel 7 was assigned to enable the auto tune feature during flight of the hexacopter in an altitude hold mode. It twitched about 20 degrees left and right for about 7 minutes and again repeated the same thing in forward and back for about 5 minutes and stopped at a stable position, completely horizontal to ground, when the tuning was done.

## 6. CAMERA ASSEMBLY AND VIDEO TRANSMISSION

For surveillance, the hexacopter uses a 7" monitor for live data feed of the camera. The camera was a Full HD LCD wifi Sports camera with 1080P resolution and $170^0$ wide view angle, capable of recording 1920*1080 at 30fps or, 1280*720 at 60fps, according to the need.

Boscam 5.8Ghz 200mW transmitter was used to transmit the video to the ground station. This system is good for up to 500m flying with the supplied antenna. An optional directional antenna can extend the range to over 2km.

Fig.16: HD Sports camera (left), video transmitter (right)

At the ground control station (besides laptop for monitoring the hexacopter, which was described previously), a 7 inch 5.8G Receiver Integrated FPV Monitor was used. Integrated receiver reduces the overall complexity at the ground, making it almost portable during operations.

The camera is mounted on a 3-axis gimbal, having capacity of Pan/Tilt/Yaw based on operators. The floor of the gimbal is equipped with vibration damping material for eliminating motor vibration that may cause noise during recording and transmission.

Fig.17: 5.8G Receiver Integrated FPV 7” Monitor

Fig.18: 3-axis Gimbal for camera

## 7. PLANNING A MISSION FOR TEST FLIGHT

After the assembly, initial setup and ground video transmission testing, autonomous flight path was setup using Misiion Planner’s FLIGHT PLAN tab. The test flight took place on the Sea beach at Fouzdarhat, Chittagong. Total 5 waypoints were setup starting with takeoff and ending with land command. A three $360^0$ turned loiter was also set at no. 3 waypoint. The default altitude was set to 10 meters above sea level. The flight plan is given in Fig.20.

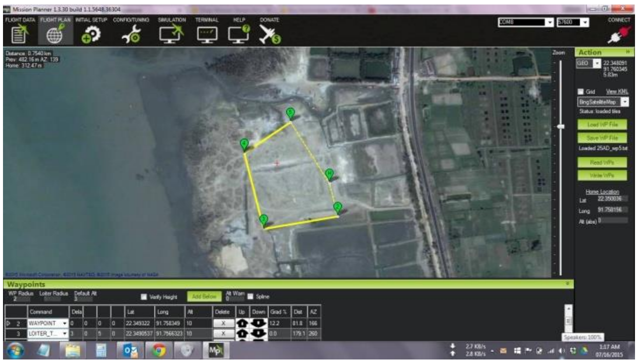

Fig.19: Mission plan for the Hexacopter at Sea beach of Fouzdarhat, Chittagong

## 8. PERFORMANCE AND DESIGN PARAMETERS

The overall design and performance parameters of the hexacopter is given in Table 2 and Table 3 respectively

Table 2: Performance Parameters

| | |
|---|---|
| Weight (Battery Included) | 2935 g |
| Battery | Type : LiPo 4S 25C<br>Capacity : 5000 mAh<br>Voltage : 14.8 V<br>Energy : 74 Wh |
| Max Propeller RPM | 14280 |
| Diagonal Distance | 550 mm |
| Camera | High Definition Sports Camera |
| Remote Controller | FlySky TH-9X 2.4 GHz |
| Pilot App | Mission Planner |

Table 3: Design Parameters

| | |
|---|---|
| Max Flight Time | Approximately 10 minutes |
| Max Wind Speed Resistance | 50 km/h |
| Max Thrust | 3800 grams |
| Pay load capacity | 1500 grams |
| Hovering Accuracy (GPS mode) | Vertical: 0.5 m<br>Horizontal: 2.5 m |
| Controllable Range | Pitch: -90° to +30°<br>Pan: ±320° |
| Transmitting Distance (outdoor and unobstructed) | 1.5 km |
| Telemetry Distance | 1.2 km |

## 9. CONCLUSION

This work represents the entire design and fabrication of a surveillance hexacopter. It has been designed to serve a specific mission but following similar approach hexacopter can be designed and fabricated for other missions also. If proper patronization is achieved, then hexacopter can be utilized in versatile fields such as surveying and reporting, industrial inspection and monitoring, site and land mapping, police evidence capture and reporting, emergency services, search and rescue, aerial photography. Thus it holds a great possibility of initializing a new era and here lays the importance of such work.

## 10. ACKOWLEDGEMENT

The team is thankful to MMRC Technology Ltd. for funding the full project and giving continuous support in every case.

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