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Development of Autopilot for VTOL application

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***Abstract*— In the ever expanding field of machine assisting humans, flight of an aircraft is one of those branches that cause fair amount of head turns. One of the interests is the ability of the software programmed aircraft control system arriving at decisions for flight control in either a military or civilian application. This paper presents the development of autopilot system for an autonomous unmanned aerial vehicle (UAV) hexarotor model with vertical take-off and landing (VTOL) ability. The overall system consists of the hexacopter with an on-board computer which is Ardupilot Mega 2560 (APM) and a second computer serving as a ground control station (GCS). The APM controls the trajectory path while mission planning and user interaction takes place at GCS. The autonomous behavior of hexacopter is established by the Inertial Measurement Unit (IMU) which comprises of MEMS based sensors like accelerometer, magnetometer, and gyroscope. The designed autopilot was successfully tested to prove autonomous maneuver with a payload carrying capacity of 2.5 kilograms and an endurance time of 25-30 minutes. The monitoring of the Hexacopter is done with the help of Mission Planner (MP) software which also enables us to graph various parameters of the flight. The hardware and software used to autonomously pilot the hexacopter are described in detailed in this paper.**

***Index Terms*—Autopilot system, APM, VTOL, Mission Planner.**

I. INTRODUCTION

The growing interest for the robotics research community in Vertical Take-Off and Landing (VTOL) vehicles as exemplified by multi-rotors, ducted-fan tail-sitters, and helicopters, is partly due to the numerous applications that can be addressed with such systems like surveillance, inspection, or mapping. The main problem which was inherent in the first multirotor helicopter which appeared in 1923 (De Bothezat) was its inherent instability and pilot workload which was extremely high [1]. The first multirotor that was commercially available was hobbyist multirotor Dragan flyer that came in 2000 [2]. Today's multirotor UAVs seem to be RC controlled toys which are capable to carry one to two kilograms payload [3]. To maintain the stability of the copter, the PID values along the roll, pitch and yaw axis are fixed by doing tethered flight simulation. In this paper the Hexacopter is considered whose six rotors are located on the six vertices of the hexagon and are equidistant from the center of gravity (CoG); moreover the propulsion system consist of three pairs of counter rotating fixed pitched blades . For controlling the attitude of the copter we use PID controlling technique [4], which is a vital inherent feature of MP software.

A multirotor is an UAV analogous to the traditional helicopter except the number of rotors is more than two. Multirotors can be classified as tricopter, quadcopter, hexacopter or octocopter with number of rotors as three, four, six and eight respectively. The lifting capacity of the copter can be increased by increasing the number of rotors. If the application requires carrying an expensive instrument; a hexacopter of octocopter is suitable as it will elude a crash even if one motor fails. The hexacopter can maintain its balance even after a motor failure because the thrust provided by the remaining five motors is large enough than single motor. The drones or multirotors have proven to be a hot area research now-a-days owing to their exceptional features like flexibility, maneuverability and payload carrying capacity. Aerial photography, remote sensing, and surveillance are some of their commercial uses today. All multirotors belong to the families of VTOL and UAV except for a few. They can either be manually controlled with a radio controller or operate autonomously on their own.

II. STRUCTURE OF HEXACOPTER

The developed hexacopter in Fig. 1 can flight autonomously as a self-organized system with the designed autopilot. The UAVs should be inexpensive and expendable. As the primary objective of this copter is for military applications, the sensors with miniature size and light weight capable of performing operation at street level were to be selected [5]. So MEMS based sensors was the best selection. . Golden Eye [6] is an example of VTOL MAV that was put in for commercial use.

Figure 1: Structure of Hexacopter

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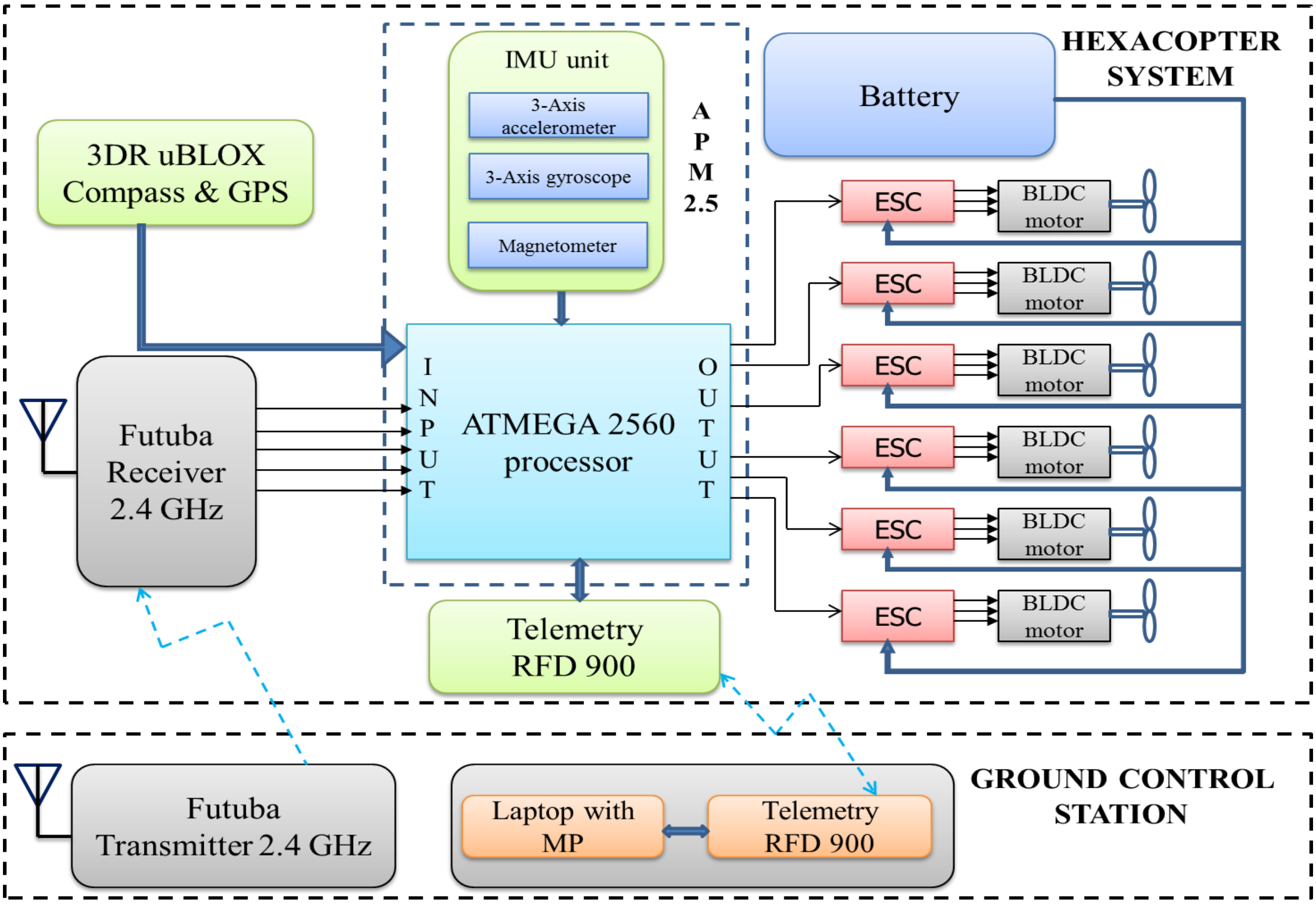

Figure 2: Overview of System

A kind of VTOL proto-type hexacopter is developed to meet the requirements. The copters body is extremely light weight for using carbon fiber reinforced plastic (CFRP) as its airframe material. The UAV is axially symmetrical rotorcraft with a six 2-Blade propellers that can produce enough thrust required when propelled by the brushless electric motor installed below it. The lithium-polymer battery that provides power to the brushless electric motor is mounted at the center of the fuselage. The electric speed control installed inside the body of UAV is used for changing the RPM of the brushless motor to alter thrust. It's very suitable for civilian and military observation and investigations missions over densely populated areas.

The autopilot designed for the purpose of making UAV to form a VTOL system is installed at the top of the structure. The additional components and extra weight placed well below the initial center of gravity will enhance the stability of the UAV. The structure of hexacopter is shown in Figure 1. A complete system overview can be shown in Fig. 2.

III. THE AUTOPILOT SYSTEM

The development of autopilot with increased payload capacity, high precision and reliability is critical to the successful deployment of VTOL. To achieve the goal of making the hexacopter, the autopilot should not only have capabilities of autonomous control and navigation, vertical take-off and landing, but also have characteristic of, real time communication and information sharing. These requirements make the design of autopilot much more challenging.

To satisfy the needs of such VTOL system, the autopilot ought to have microprocessor with high computing capability, multiple interfaces connecting with all kinds of sensors, actuators, and communication devices.

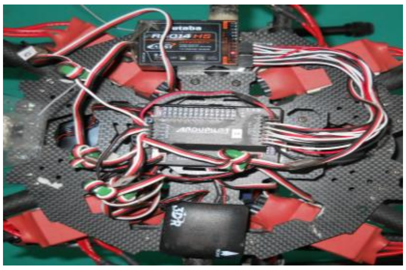

Figure 3: Structure of Autopilot

The high performance microcontroller APM 2560 having advanced RISC architecture with a wealth of on-chip peripherals, such as the on-chip ADC, the PWM output, SCI, SPI, CAN [7] and so on has been selected. The autopilot structure is shown above in Fig. 3.

During the initial stage of configuration of the APM, the MP asks to select frame layout of the motor orientation and the APM. Out of the two layouts provided that are “Hexa +” and “Hexa X”, we selected the “Hexa X” configuration because it is more sensitive to the roll axis. The two configurations are shown in Fig. 4. The vertically opposite motors rotate in opposite direction to cancel the torque produced which gives thrust to the hexacopter.

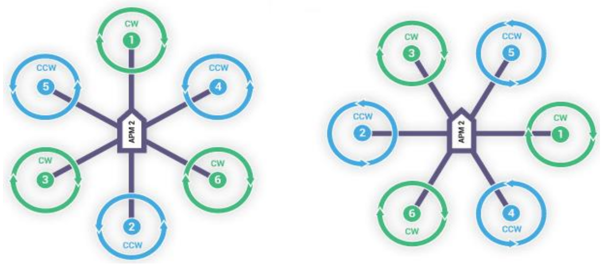

Figure 4: Frame layout

The hexacopter can be flown in different modes using manual control. In the standard mode, hexacopter attitude (roll and pitch), yaw rate and thrust are manipulated with a standard flight RC-radio unit. The APM estimates attitude, altitude and yaw using on-board sensors. The individual components of the system depicted in Fig. 2 are described below.

A. APM 2560

The APM 2.5 has an ATmega2560 microprocessor along with power electronics, flash data storage and programming logics shown in Fig. 5.

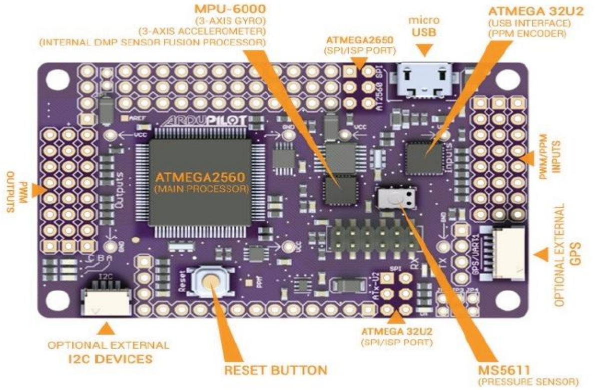

Figure 5: APM 2.5

The onboard inertial measurement unit (IMU) i.e. MPU 6000 features a three-axis accelerometer, a gyroscope and a magnetometer. The IMU along with ATMEGA 2560 processor together comprises the APM. These sensors are used for attitude and yaw estimation. A barometer and an external sonar sensor enable altitude measurements and an external GPS receiver is used for outdoor position measurements. It contains onboard 4 MB Data flash chip for automatic data logging.

B. 3DR uBlox

The 3DR uBlox module comprises the GPS and compass.

1) GPS

The GPS lock is performed when it gets at least six satellite signals. It is indicated by a blue LED glowing solid on it. The hdop (horizontal dilution of position) value gives the accuracy of the GPS location which is displayed in MP. The hdop value should be less than two.

2) Magnetometer

The magnetometer gives the position of the copter relative to the horizontal position. The angle through which the copter moves i.e. bank angle is shown in the MP window. This data is also communicated to the GCS through telemetry.

C. RFD 900 Telemetry

The RFD 900 telemetry shown in Fig. 6 is used for data logging purpose to monitor the health of copter through MP. It provides compact yet powerful data communication. The operating frequency range is 902-928 MHz while the outdoor line-of-sight range is 40 Km or more depending on the antennas. The antenna used is 900 MHz half wave dipole antenna. The air data rate speeds is up to 250 kbps.

Figure 6: RFD 900 Telemetry

D. Futuba Transmitter and Receiver

The Futuba 10C 10CG 10 CAG 2.4 GHz in Fig. 7(a) is used to control the motion of the hexacopter. The left stick is used for throttle and rudder while the right one is used for aileron and elevator controls. The two switches on the top are used for selecting the modes which are illustrated in Table I.

(a) (b)

Figure 7: (a) Futuba Transmitter, (b) Futuba Receiver.

The Futaba R6208SB 2.4GHz FASST 8-Channel Receiver in Fig. 7(b) is used to receive and decode the control signals from the transmitter and send it to the processor to take the necessary actions to control the copter. The first four channels are used for aileron, elevator, throttle & rudder respectively. The fifth channel is used for setting the modes of the flight while the sixth channel is used for the stability of copter.

Table I. Flight modes

Mode	Mode name	PWM
1.	Auto	0-1230
2.	Altitude hold	1231-1360
3.	Position	1361-1490
4.	RTL	1491-1620
5.	Land	1621-1749
6.	Stabilize	1750+

E. The Propulsion System

The propulsion system comprises of the ESCs, brushless motors and the propellers.

1) *Propellers*

The propellers used are 15 X 10 inch (diameter X pitch) slow flight propellers. It is shown in Fig. 8. Longer propeller blades have a higher aspect ratio which gives it a better lift to drag ratio. The propeller is made up of carbon fiber material.

Figure 8: Propeller

2) *BLDC motors*

In our project we have used the BLDC motor of 500kv of out runner type. They are capable of rotating up to 18400 RPM without any load. A brushless motor cannot be driven directly by a PWM signal. It is instead controlled by an ESC. It is shown below in Fig. 9. Also the thrust provided by a motor is 4.67 Kilograms. . Due to the location of the stator windings, outer rotor Brushless DC motors typically operate at lower duty cycles or at a lower rated current.

Figure 9: BLDC Motor

3) *ESCs*

The ESCs used in this project is Turnigy Plush 60A with inbuilt BEC (battery elimination circuit) of 3A/5V. The ESC receives a PWM signal from the flight board and controls the motors by rapidly turning on and off the current to the different poles in the motor. It is shown below in Fig. 10. They have a broad range of programming features and a smooth throttle response compared to other BESCs in the same price range. This BESC can handle 3A continuous current.

Figure 10: ESC

F. *Battery*

The six cell Li-Po battery of 1300mAh is sufficient to drive the copter with endurance up to 15-20 minutes. As we have shorted the JP1 jumper of APM we need a single power supply for inputs and outputs. The built in BEC allows us to supply power backwards from motor side to receiver side. The stacking construction gives more reliable voltage.

IV. HEXACOPTER TESTING

The hexacopter testing comprises of PID tuning and flight monitoring explained below.

A. *PID Tuning*

The hexacopter developed is very unstable in air during its flight. To adjust its stability we had set the PID values of the gain along three axis of motion i.e. roll, pitch and yaw. For this we select the channel six of receiver. The developed Hexacopter was tied as shown in Fig. 11 for tethered flight.

Figure 11: Tethered flight

First the throttle is increased so that the copter will attain a specific height. After the desired height is attained the copter is sent in Altitude hold mode. The abnormal behavior of the copter was very much evident. Then we changed the gain value by the knob on the transmitter for channel six in the extended tuning of MP till we get the copter balanced in the respective axis. The finalized PID values of the gain are to be saved in APM by pressing write parameter option in MP. This task was done in real time due to the use of RFD 900 telemetry. The finalized PID for rate/roll gain values are shown in Table II.

Table II. PID values

	Roll	**Pitch**	**Yaw**
P	0.1500	0.1500	0.2000
I	0.1000	0.1000	0.0200
D	0.0040	0.0040	0.0000

B. *Flight Monitoring*

Once the copter is ready to takeoff, we have to first Arm the APM in MP. Now the various sensor values will start to appear in the GUI of MP. The MP window is shown in figure12. We can also set way points on the map provided there, through which the copter will go when in guided mode. After the copter has landed, we can download the telemetry logs form the APM which contains all the flight details. Through these logs we can plot the graphs of the roll, pitch and yaw axis as shown in Fig. 13. From the graph we can very much conclude that the roll axis (red) change in correlation with the pitch axis (green) concluding that the developed hexacopter is stable. The path that the copter tracks is shown by violet color as shown is Fig. 12. Also the air speed, latitude, longitude, battery status, current heading etc., are shown in Fig. 12.

Figure 12: Mission Planner Window

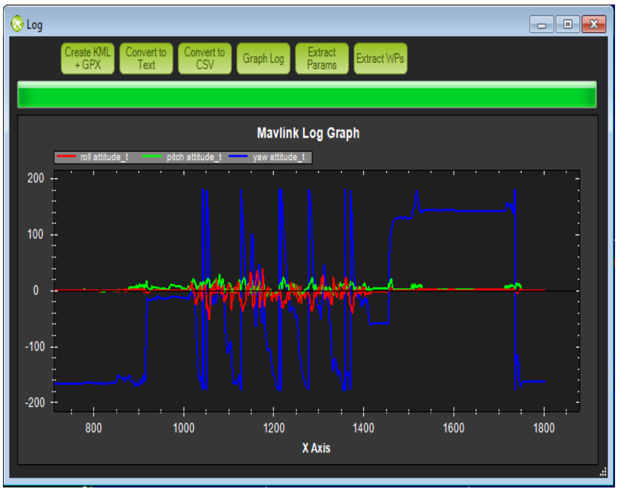

Figure 13: Log Graph.

V. PERFORMANCE EVALUATION

The developed hexacopter is evaluated for its performance with respect to various parameters as shown in Table III. It is found that the power requirement of the hexacopter is reduced selectively with the increased payload handling capability. Also the time to hover endurance is increased than the standard quadcopter.

This makes the copter perfect enough to carry expensive instruments required for military applications.

Table III. Performance evaluation

Parameter	Hexacopter	Units
Propeller X It's diameter	6 X 15	inch
Motor + ESC efficiency	80	%
Power required /motor (100%)	750	Watt
Thrust	4.365	Kg
Total power to take-off (50%)	2250	Watt
Total power to hover (35%)	1575	Watt
Mass of structure	1.20	Kg
Payload carrying capacity	2.5	Kg
Total mass UAV	5.47	Kg
Endurance	25	Min

VI. CONCLUSION

The paper has presented the design and development of autopilot system for UAV hexacopter model using on-board computing and has been successfully tested for hovering flight. The low power consumption and increased payload capacity of hexacopter distinguished this project from others which were not suitable for carrying expensive instruments. The stabilization of hexacopter heading, pitch, roll and altitude has all been successfully demonstrated and this shows the possible achievement towards the development of autonomous UAV.

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