Design & Implementation of an UAV (Drone) with Flight Data Record

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Abstract— **This paper proposed the development of an autonomous unmanned aerial vehicle (UAV) which is controlled by wireless technology through graphical user interface (GUI). This proposed design capable to fly autonomously and also capable to track pre loaded mission automatically. Proposed mathematical model and artificial algorithm control technique by which quad rotor can capable to fly autonomously, trajectory tracking, graceful motion and accurate altitude hold performance. In this system author used IMU 9DOF (3-axis accelerometer, 3-axis gyroscope & 3-axis magnetometer) which ensure it smooth movement, graceful motion and trajectory tracing. GPS system and barometric sensor make it more efficient in autonomous mode. Several PID loops designed to get better stability and performance in different mode. All signals are processed by a powerful high speed controller board which makes it more efficient and effective. This work aimed to design a quad copter that will try stable its position according to preferred altitude. Also here stability check has been done with pitch and roll. All data and result discussed at the end of paper.**

Keywords—**autonomous UAV system, inertial measurement unit, graphical user interface, PID controls loops, stability and performance.**

I. INTRODUCTION

At present world drone technology is very familiar & versatile technology. Drone can drift in air .We can also use wireless camera with it. So that we can use it to do different types of tasks. Nowadays Drones are used in long range wars as a weapon and also as a helper of fighter in the war. Scientist use drone as a part of their research assistant. Drones not only help us in society but also a threat for us, as because many of developed countries use it as their weapon of destruction. So drones have their ability to predetermined work so that it becomes important in today's world. [1]

Drone has many importances but it also creates some questions about privacy. So for this issue many governments declared some rules and regulation to fly drone in different purposes. A mature quad rotor system can use for educational and experimental porpoise [2], [3]. Photo shoot for films & drama are also use drone.

At past drones was used only by military in their war. But day by day it is now used in various household works as it operation and control become easy day by day. Developed world and also developing world use it for their own purposes. Uses of drone are rapidly increased for both public & Private sector. Peoples of Canada & North America now use drone as their assistant of housework & office work. At present not only in Canada but also in others countries drone technology increasing day by day.

For the domestic user they have to pay attention on government rules regarding use of drone. For this propose small & cost effectives drones are available in markets. Its popularity increased day by day.

A. *Applications of UAV(Drone)*

There are some many important activates of drones. Which are:

- National security
- As a long range weapon of military war
- Public safety
- Environmental research
- Scientific research
- Small household work.

B. *Related Works*

In recent years many scientist works into this area of UAV. As in reference paper [5], [6], [7], Samir Bouabdallah et al. make a good number of research on smart controlling if UAV. This author also used back stepping method [7]. For a better solution in stability & smooth controlling many scientists used PID and root locus method [8]. PD controller is also a very popular method for control drone & robotic arm [9]. Many scientist use PD control as their experimental platform [1], [10]

II. PROPOSED DESIGN

A. *System Overview*

To desing a stable multicopter we need maintain some physics, mathmatics and aeirodynamic term. Aerodynamic help to define its movement and inertial motion. In the other hand mathematical calculation helps to manipulate required lift

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force, angular position, graceful motion and trajectory definition.

We designed drone's body according with dynamics and also designed artificial algorithm to make it autonomous and well behaved. Hardwire system consists of different sensors, powerful controller unit and electronic equipments so on. For a desire movement controller takes data from different sensors. 3-axis accelerometer and 3-axis gyroscope provide data of its orientation, acceleration and angular rate. Then these data processed and compare with reference and desire value. This operation performs with the help of PID loop. Several PID loops used in these case like pitch control, roll control, yaw control, hover, altitude holding and orientation control. IMU (inertial measurement unit) provides real altitude, angular movement and orientation. After that required pulse sends to ESC (Electronic Speed Controller) for desire speed of rotation. Magnetometer provides real time direction with the global magnetic field reference. Barometric pressure sensor also provides real time altitude. GPS (global position system) module helps to make system autonomy. It helps find out any coordinate and reach to this coordinate. Telemetry kit helps to observe flight data wirelessly from ground station. It also send mission file and communicate with air part like USB serial mode (TTL mode).

In ground part consists of powerful ground station. PC/Laptop used for sending data through telemetry and coding or data logging from air part. Another radio transmitter used to switch different mode and operate in manual mode.

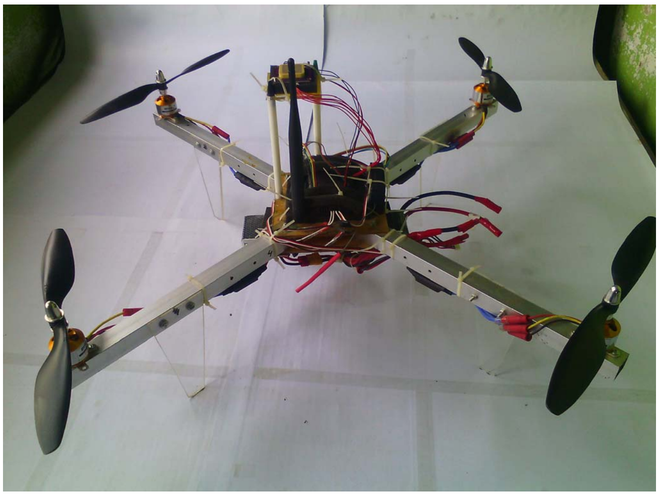

Figure 1. System Overview of Autonomous Unmanned Aerial Vehicle

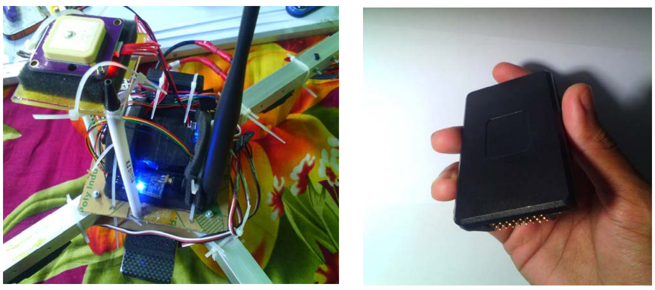

Figure 2. Air part hardware system in alive. Right figure shows Processing unit of an autonomous UAV.

B. System Block Diagram

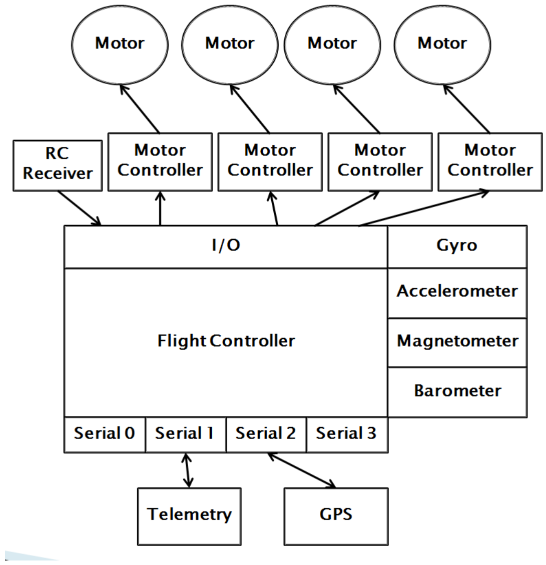

Figure 3. Proposed block diagram of UAV's air part.

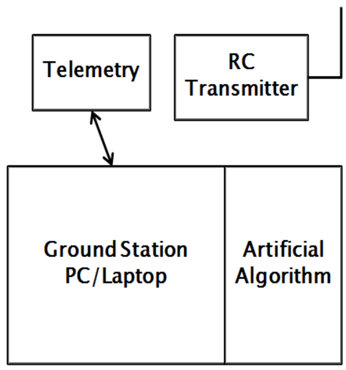

Figure 4. Proposed block diagram of UAV's ground station.

III. SYSTEM MODELING

To design a stable multi-rotor copter we have to concentrate its structure and dynamics. We have to develop a firmware in which contains different control strategy, mode of operation, data evaluation and different PID loops for stability:

A. Body Dynamics

Body dynamic of multi-rotor copter governs the response of attitude control. Let consider a multi-rotor copter frame. We can derive expression in two coordinate system i.e. one is inertial coordinates and another one is body fixed coordinates.

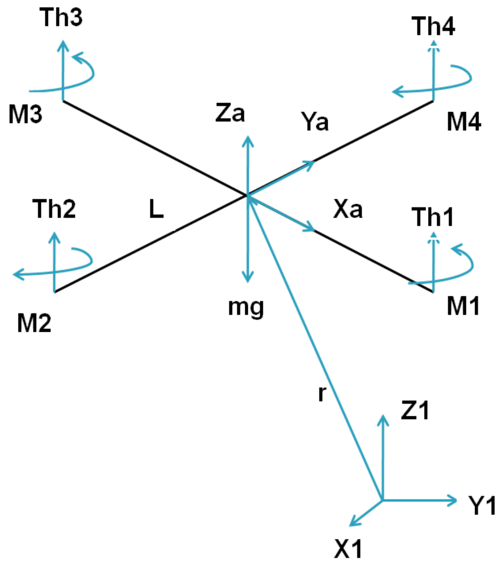

Figure 5. Force diagram of quad copter.

U1 is summation of the thrust of every individual motor. Th1, Th2, Th3 and Th4 are thrust generated by front, rear, left and right motor respectively. m is Quad-copter mass, g is marked as the gravity acceleration and L is the liver distance of Quad- copter. x, y and z are the three axis position. φ, θ, ψ are three Euler angles representing pitch, roll and yaw.

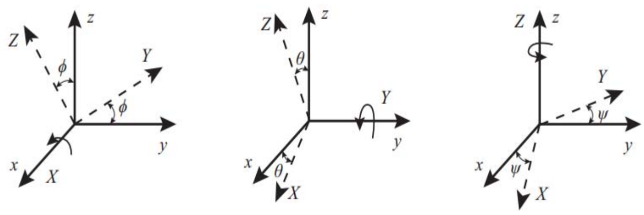

Figure 6. Attitude control definition.

From the Fig. 6 we get transformation matrix with defined attitude angles:

$$R(\theta,\phi,\psi)=\begin{bmatrix} c\psi c\theta & c\psi s\theta s\psi - s\psi c\theta & c\psi s\theta c\phi + s\psi s\phi \\ s\psi c\theta & s\psi s\theta s\phi + c\psi c\phi & s\psi s\theta c\phi - s\phi c\psi \\ -s\theta & c\theta s\phi & c\theta c\phi \end{bmatrix} \quad (1)$$

Where s represents sin, c represents cosine, and φ, θ, ψ stands for attitude angles of roll, pitch, and yaw respectively.

Direct inputs are RPM commands for every motor in body fixed coordinates. So the resultant outputs are Z directional thrusts in body fixed coordinates. Attitude & position is only concern of our outputs. U1, U2, U3 and U4 are four control variables used to eliminate this gap. Each of the affects the attitude, rotation in roll angle, rotation in pitch angle and yaw angle respectively.

$$U = \begin{cases} U1 = Th1 + Th2 + Th3 + Th4 \\ U2 = (Th3 - Th1)L \\ U3 = (Th2 - Th4)L \\ U4 = M1 + M3 - M2 - M4 \end{cases} \quad (2)$$

Here Th_i is thrust generated by four motor, M_i are momentums, and L is lever length.

By applying the force and moment balance laws, motion formulations are given as

$$\ddot{x} = \{U1(Sin\,\psi Sin\,\phi + Cos\,\psi Sin\,\theta Cos\,\phi) - K1\dot{x}\}/m$$

$$\ddot{y} = \{U1(Sin\,\psi Sin\,\theta Cos\,\phi - Cos\,\psi Sin\,\phi) - K2\dot{y}\}/m$$

$$\ddot{z} = (U1 Cos\,\phi Cos\,\theta - K3\dot{z})/m - g$$

Where k_i is drag coefficient (assume zero since drag is negligible at low speed).

The angle ϕd and ψd can determine as follows from Fig.7,

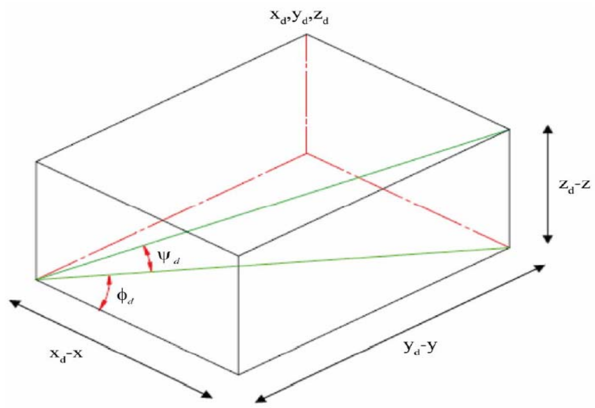

Figure 7. Angle movement of quad copter.

$$\phi d = \tan^{-1}\frac{y_d - y}{x_d - x}$$

$$\psi d = \tan^{-1}\frac{z_d - z}{\sqrt{(x_d - x)^2 + (y_d - y)^2}}$$

The second derivatives of each angle given as

$$\ddot{\phi} = U2 / I_{xx}$$

$$\ddot{\theta} = U3 / I_{yy}$$

$$\ddot{\psi} = U4 / I_{zz}$$

Where I_{xx}, I_{yy} I_{zz} is rotary inertia around X, Y, Z axis respectively

B. Aerodynamics Effect

The thrust T produced by each motor is calculated as

$$T = \rho C_T A w_m{}^2 R^2$$

Where

C_T : thrust coefficient

ρ : Air density

A: rotor disk area

R: blade radius

Propeller diameter & pitch-

$$D \sim \tau\ ,\ p \sim \tau$$

$$\tau \sim E$$

Where, d: diameter of propeller, τ : torque, E: energy

Frame parameters-

$$\text{Blade tip speed, } v \sim \sqrt{R}$$

$$\text{Lift, } F \sim R^3$$

$$\text{Inertia, } m \sim R^3, I \sim R^5$$

$$\text{Acceleration, linear } a \sim 1 \text{, angular } a \sim \frac{1}{R}$$

Where, R: frame center to motor distance

C. Dynamics of Rotor

The dynamics of DC motor is generally described as

$$L_i \frac{di}{dt} + Ri + k_e w_m = u$$

$$J \frac{dw_m}{dt} = \tau - \tau_d$$

Where

L_i : Coefficient of inductance

i: armature current

R: armature resistance

k_e : back emf constant

w_m : speed of motor

u: armature voltage

J: inertia of motor

τ : torque of motor

τ_d : load

D. System PID Control

PID (proportional-integral-derivative) is a closed-loop control system. It helps to get c our results as must as close to the actual result by responding to our inputs. Scientist uses it while controlling drone or robot for achieves stability.

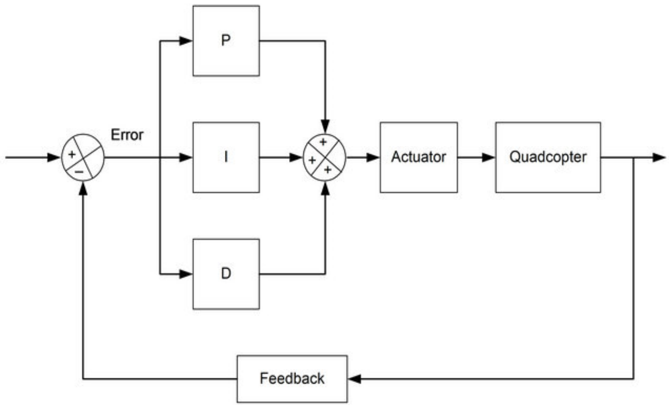

Figure 8. PID loop for system.

PID basically works with three algorithms.

- P depends on the present result
- I on the accumulation of past errors.
- D is prediction of future errors based on current data.

Different coding systems are available based on these algorithms.

Per axis PID structure shown in Fig.9. For controlling quad copter or any types of multi copters, output of sensors (like the pitch angel) is very much needed. From the sensor data we can easily estimate the error (how far we are from the desired pitch angle, e.g. horizontal, 0 degree). Then we can use PID algorithms for eliminating errors

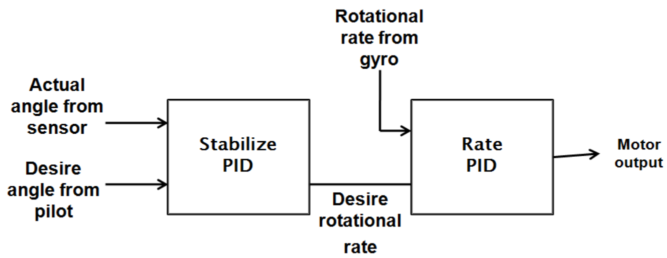

Figure 9. Per axis PID structure.

IV. Results and Implemented Design

A. On flight Simulation Data

All the data collected after 18-20 experimental fight of implemented UAV.

Fig. 10, indicates the altitude hold performance. This is one of the important curves which indicate the stability and behavior of our drone. Here Holt for desire altitude and Alt for altitude at which drone travels. This carve contains several mode of operations characteristics. When we shift from stabilize (manual) mode to hover mode or GPS lock mode then DAlt curve generate and then altitude calculated from IMU unit and also generate the barometer altitude curve shown in Fig. 11, as blue line. Alt and DAlt line lies close together that means altitude hold performance is good in different modes.

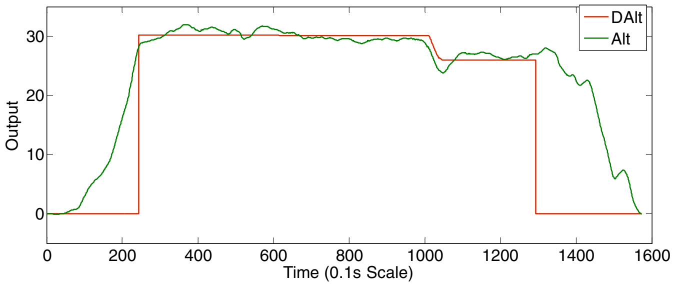

Figure 10. Altitude hold performance data in different mode.

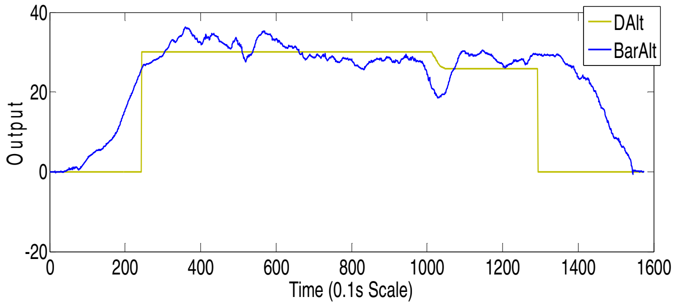

Figure 11. Altitude hold performance with barometer.

Fig. 12, shows the pitch response and Fig. 13, shows the roll response of UAV in different modes. Here, DesPitch and DesRoll for desire pitch and roll respectively. And only pitch and roll indicate the pitch roll response. If we observe the curves than we see that pitch and roll curve is similar to desire pitch and roll curve. We see in stabilize (manual) mode and altitude hold mode we get some spike which indicate pitch & roll action. Though stabilize mode is manual mode so we change pitch manually. In altitude hold mode- altitude maintain automatically but pitch & roll is also manual control. In loiter mode that means in GPS lock mode- all parameters controlled automatically without human interface. So in loiter mode spike is less which indicate it holds a constant coordinate with stability.

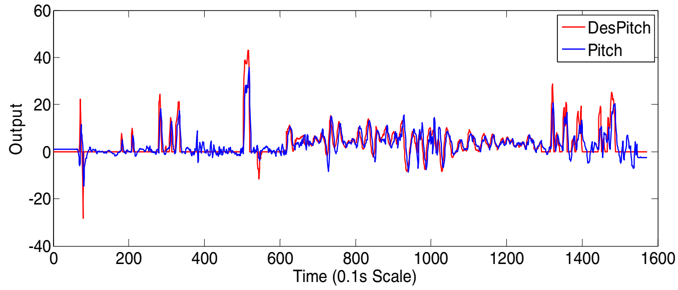

Figure 12. Response of pitch in different mode.

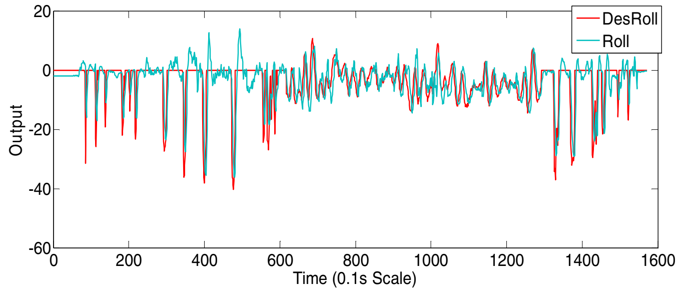

Figure 13. Response of roll in different mode.

Fig. 14, shows the throttle response in different modes. We see that throttle fluctuate in manual mode due to manual control of throttle fluctuation. In autonomous mode throttle automatically control by processor unit. So throttle response does not fluctuate significantly.

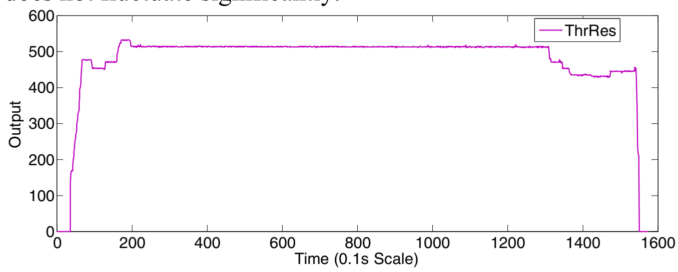

Figure 14. Throttle response of proposed design in different mode.

B. Implemented Design

Total hardware design of proposed UAV is given below.

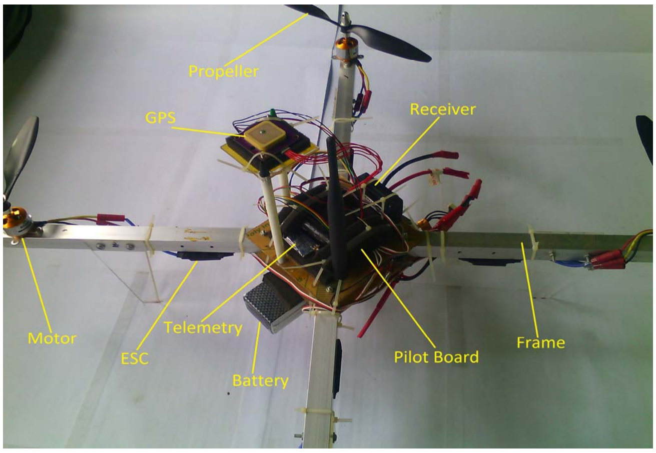

Figure 15. Real view of implemented design.

V. CONCLUSION

From all of curve analysis we can conclude that overall performance of our system is stable. This system is capable to fly in different mode without complexity. It's performance, movement, orientation, motion, stability also good. This drone is capable to fly in several modes. The main modes are manual mode, hover mode, auto mode and return to lunch mode. In manual mode drone is controlled by remote device and in others mode drone flies autonomously. This system have facility to see flight data by using powerful ground station and user can upload or override a mission in real time flight condition when a mission running. The distance between motor to motor is 0.61m. The overall total weight of implemented design is 1.46kg and its carrying capacity is 0.5kg.

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