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Analysis of the Stability of quadcopter and Control using PID controller

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Abstract*— A UAV is an avion which fly without a human pilot which can be controlled by autopilot hardware. In this work, a type of aerial vehicle called quadcopter is considered which is very agile and unstable. A helicopter can be lifted by aerodynamic principle acting upon wings but quadcopter can't lift like helicopter any one of the motor failure or speed of the four motor mismatches will lead to a severe accident. As a result, it's highly challenging for a human to control the flying quadcopter by controlling every motor directly, for this reason, they move for classic piloting method to achieve extreme reaction speed and attention. The scope of this paper is to develop an autonomous quadcopter using a PID controller which has a capacity of stable flying in the air with the help of using a microcontroller-based control mechanism. That can be done by measuring Euler angles to produce a control signal to the quadcopter to control its position and velocity. The Quadcopter is designed to be small enough so that cost would be minimized.

Keywords*— Quadcopter, UAV, Euler angles, Stability, PID controller.

I. INTRODUCTION

Over the last few decades, the fabricating and selling the remote control UAV named as quadcopters has huge growth in flying technology. The Vehicles contain four arms with propellers blades and brushless DC motors arranged in "X" or "+" structure is named as quadcopter where "X" is the most adopted structure. The quadcopter also termed as Drones, Quadrotors or Multicopter. The quadcopter is designed with well-optimized balanced structure will be elected for an easy balancing mechanism and reduce failures caused due to less intensive vibrations made by propellers blades. The objective of the paper is to design a flight controller by implementing PID algorithm which calculates the output values of the motor with the help of input values received from transmitter and sensors [2]. Initially Inertial Measurement Unit (IMU) sensor will give current angles and angular velocities data to the controller at the same time human or robot present in the ground will control the UAVs by a radio frequency signal which is transmitted by the transmitter by getting the data our PID controller will produce some value to keep the quadcopter in stable itself in air medium. Some UAV's can be designed to control the movement autonomously.[9]

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The autonomous control is termed as navigating the UAV's to a target location to achieve less deviation from the given path to the target location without any signal sent by the human or robot present in the ground. the quadcopter should be controlled by keeping its balance according to the reference level momentarily.

[3] Many research is going on designing the number of arms present in UAV's some names are Tricopters, Hexacopters, and Qctocopters (with eight arms). Now a day the use of quadcopter is get increased in aerial surveillance, agriculture (pesticide sprinkling monitor the field), goods delivery purpose, Photography etc. [8]

II. OVERALL BLOCK DIAGRAM & ITS DESCRIPTIONS

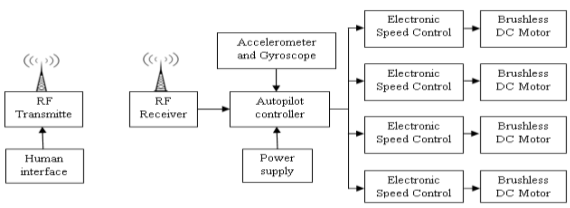

Fig 1. Overall System layout

The above fig.1 shows the overall design of our work. The autopilot controller used in the work is controlled by a ATmega328 microcontroller. Initially, the radio frequency signal is given through a transmitter in the ground station which will be received by a quadcopter radio frequency receiver which fetches to autopilot controller. At the same time, the current status of the quadcopter will be taken from the sensor MPU6050. The autopilot controller which compares the current status data with data transmitted by human be interface in the ground station. The inaccuracy signal is given to the PID controller which will take the necessary corrective action to make the quadcopter will balance in the air by calculating the power should be dissipated to each motor. Here brushless DC motor is used for speed control. The 2.4GHz RF signal is used for communication with 6 channels of which 4 channels were used for controlling the motors and the propellers. [5]

III. HARDWARE AND DESCRIPTIONS

A. Controller Section

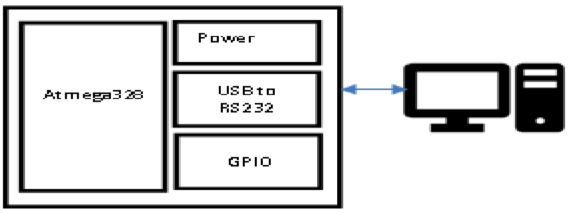

Fig.2. Controller Hardware

The ATmega328 is a generally preferred microcontroller for UAV applications. This ATmega328 IC contains 14 Digital input and output (I/O) pins and 6 Analog pins that may be used to various developments for other circuits. This IC is programmed by AVR Studio IDE software given by Atmel using AVR programmer. It could be powered by an external 9-12 volt battery supply. It will have the capacity to withstand 7-20 volts. The above Fig.2 show Controller hardware layout.

B. IMU

An Inertial Measurement Unit (IMU) is an electronic device which is used to collect angular rate, specific force and magnetic field present around the body, with the help of the combination of accelerometers, gyroscopes with magnetometers.

The MPU6050 is small package module designed using MEMS technology which contains 6-axis Motion capture Device where 3-axis is used for Gyroscope and remaining 3-axis is used for Accelerometer also this nodule contains in-built on-chip Digital Signal Processor in it. This module will communicate with microcontroller using an I²C communication protocol to transfer the collected information from the axis. The data collected will be converted to digital form by using ADC for each channel. This module can capture the 3-axis data and conversion will happen at the same instant. IMU (inertial measurement unit) is used to provide input to the flight controller to make the quadcopter self-balancing. The MPU6050 is an IMU that contains a gyroscope, an accelerometer, and a digital signal processor for determining 3D angles and angular velocity. The MPU-6050 has the combined capability of both an accelerometer and a gyro.

C. Eectronic Speed Control (ESC)

The electronic speed control (ESC) is electronic hardware which is used to controls and adjusts the speed of a brushless DC motor. This unit is not only used to adjust the speed is will helped in the braking system of the motor. The SimonK 30A ESC used in this work.

The ESC performs multiple functions such as powering the quadcopter receiver and the motor with a single power source itself that will lead to eliminating the designing different power circuits for receiver used in a quadcopter. Secondly, it will transmit the data to the flight controller which is received from the ground which helps to give the correct power to the motor. The controller will produce a pulse PWM signal which is applied in ESC to vary the speed of the brushless motors which resulted in drive the propellers attached with it. there are many ranges of ESC available in the market to control the different RPM of the motor for different size propeller it is necessary to find correct ESC for the quadcopter while choosing it to consider source current of it. For this work 30A ESC is used for the Quadcopter.

D. Brushless DC motor

The Brushless DC motor also known as high-speed motors as they do not use brushes for commutation. This kind of motors will produce huge speed range in a short duration due to a large amount of torque produce initially. In this type of motors, the problem of passing current to the armature is overcome by making the armature as fixed since armature is fixed permanent magnets rotate around it. Wide range of RPM is available in the market for where 1000KV BLDC is used for our quadcopter.

E. RF Transmitter & Receiver

The transmitter (radio controller) is used by the pilot to send input to the quadcopter to control where it should fly. FLYSKY FS-T4B 2.4GHZ 6 channel transmitter and receiver is used in this work but only 4 channels are used. Through this RC transmitter it is possible to control the direction and place where the quadcopter is located now by receiving data coming from the pilot may be a human or robot present in the ground. One important thing to do note before using is transmitter-receiver pair should be calibrated before putting to use. 2.4 GHz RC radio transmitter and receiver is used for one way communication that means receiver didn't give any signal to the transmitter available in the ground.

F. Lithium Polymer Battery

Lithium Polymer battery is one kind of rechargeable battery this type of battery is used in quadcopter for some technical reasons such as light in weight, dissipate high power, the capacity of holding a huge amount of power in it and their recharging method. HJ Power 11.1V 2200mAh 35C Lithium Polymer Battery is used in this work.

G. Quadcopter frame

The F450 frame which is used is made of plastic and fiberglass. It includes an integrated Power Distribution Board. These frames only hold the ESC and motor of quadcopter also it helps the quadcopter to lift-up from ground. This frame is available in different shape and a different size in the market. The quadcopter frame of 450mm size quadcopter F450 is used in this work.

H. Propeller

Every motor used in the quadcopter is associated with a propeller to produce thrust. Generally, quadcopter use two clockwise and two anticlockwise propellers. The reason is the torque produced by motor should be the same which can make the quadcopter to stability flying in the air. If the entire propellers which rotate in the same direction then quadcopter never produce trust as the result it can't stably fly in the air. The propellers come in different diameters and pitches. 1045 – 10″ diameter and 4.5″ pitch are used in this work.

IV. QUADCOPTER MOVEMENTS

The Stability and control are more complex for a quadcopter. Two clockwise and two anticlockwise rotation motors were used in this work to make lifting force equal while flying in the air [2][6]. The quadcopter can move freely in three dimensions movement they are given by

- Roll.
- Pitch.
- Yaw.

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The different types of movements of the quadcopter are shown in below fig.3.

A. Pitch Movement

Pitch is controlled by rising or sink the speed of the front side or back side motors which lead the quadcopter to pitch to up or downward directions.

B. Roll Movement

Roll is controlled by rising or sink the speed of the right side or left side motors which lead the quadcopter to roll in right or left directions.

C. Yaw Movement

Yaw is controlled by the rotating of the quadcopter either to the right or left side. It will help the quadcopter movement to spin in the left or right side by rising or sink the speed of clockwise or counterclockwise rotating motors.

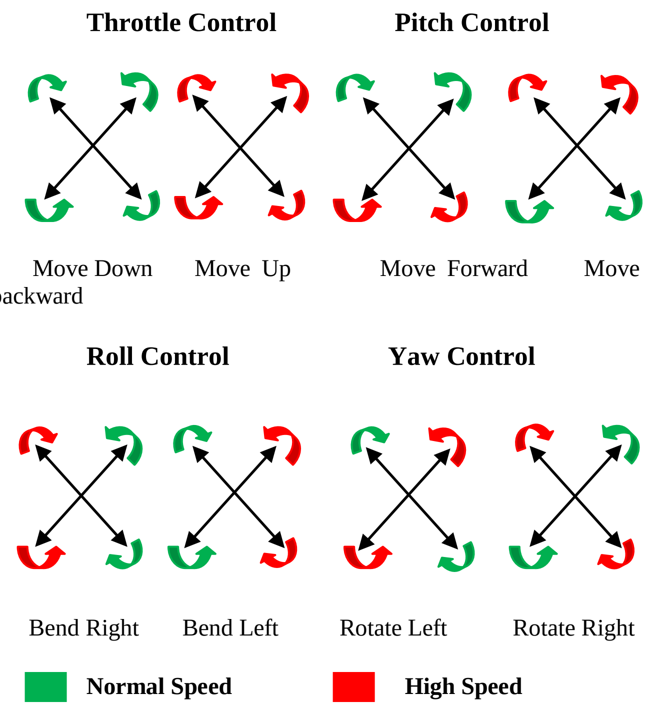

Fig.3. Quadcopter Movements

V. DESIGN METHODOLOGY

A. Design & Calibration of IMU

The MPU6050 module communicates with the controller board through I²C serial communication via the serial clock (SCL) and data (SDA) and configures the module as a master at a maximum speed of 400 kHz.

Initially, MPU6050 is in sleep mode and one should enable it. Sleep mode is disabled by writing zero to the sleep register. After disabled one can read the registers for the raw values of accelerometer and gyro. Around 2000 samples of 3-axis will be taken from MPU6050 for the entire data is used and averaged to avoid error during the starting phase. The values are retrieved from the MPU6050 is stored in respective registers. Computation of roll and pitch is done after getting the sensor value to check the quadcopter movement based on its axis. The error signal is then given to the PID controller which will produce a necessary decision on quadcopter stability. [7]

Fig.4. Serial monitor data for calibrating MPU6050 with Quadcopter

Fig.4. shown above is the calibration of gyro when it is interfaced with the controller. When it is moved right side arm of the quadcopter upward or downward check whether the gyro sensed it correctly. Similarly, the same testing was done for Nose upward and downward (pitch) directions and also for move left and right directions (yaw). Thus, in this way, all the directions of the gyro interfaced with controller were calibrated well before the flight is ready to take off.

B. Design & Calibration of RF Transmitter and receiver

Initially, before using the RF transmitter and receiver on quadcopter initial binding has to be done. After binding each other all the transmitter sticks position should be calibrated. The transmitter sticks calibration is shown in below fig.5. Initially, the RC receiver produces output as pulse width modulated (PWM) signals on each channel. In this Work, the RF receiver to controller unit digital pins 8, 9, 10, 11 were used for the connection. Each channel of the receiver is assigned a control. Channel 1 is used for roll movement channel 2 is used for pitch movement channel 3 for throttle movement and finally, channel 4 for yaw control. The PWM pulses from receiver generally range between one and two milliseconds long. When the transmitter is at full throttle the output will be of 2000 microseconds. During neutral it is 1500 microseconds when the throttle is at a low position the output is around 1000 microseconds.

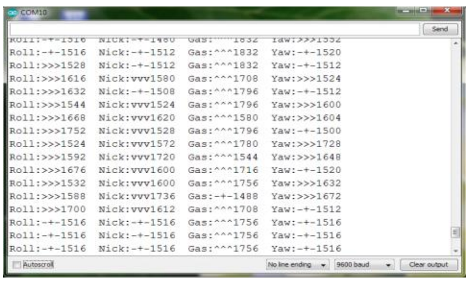

Fig.5. Serial monitor data for calibrating transmitter stick position

For reading the input from the receiver it is necessary to attach interrupt to the controller unit pin which is connected to the RF Receiver. The pins interfaced with controller and receiver would trigger an input. It would then fire the pin change interrupt leading to the execution of Interrupt Service Routine (ISR)[4].

In the ISR input signal is checked as high or low. If high means timer is started and if low means timer is stopped. The difference in the time gives the width of Pulse Width Modulation wave which is exactly same what value is transmitted by the RF receiver.

C. Calibration of ESC

ESC means Electronic Speed control. The ESC has a 5v source, a ground and a signal line. ESC is programmed first writing the maximum Pulse Width Modulation signal of 2000 microseconds and then waiting for the signal and then enters the minimum Pulse Width Modulation signal 1000 microseconds.

Calibrating ESC Unit Flow Chart

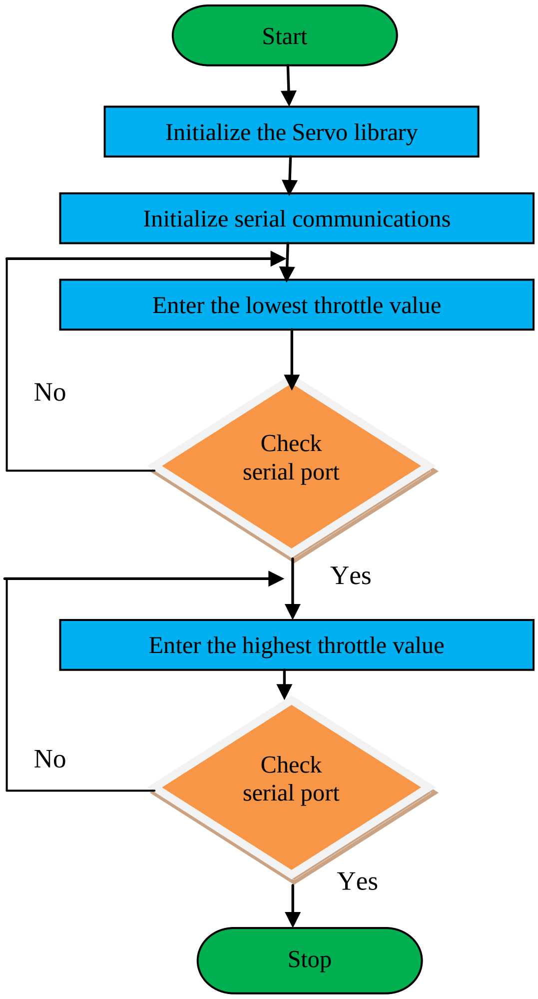

Fig.6. Flow chart for calibrating ESC

In first method after uploading the code, the ESC connects with the controller with the corresponding pin designated in the code. Lowest throttle value 1000 microseconds and then with 2000 microseconds is used initially, later ESC with any input from 1msec to 2 msec.In the second method it is necessary to connect the battery eliminating circuit of ESC with RF receiver and put the throttle in high position then connect the battery to ESC after hearing double beam sound. Put the throttle stick back to low that it. ESC is calibrated to the maximum and minimum value.

D. Design calculation for battery discharge rate

Batteries made by NiCad materials contain 1.2 volts per cell but Batteries made by LiPo materials contain 3.7 volts per cells which result in getting different voltage by multiples of it, for example, 7.4V, and 11.1V batteries.

The LiPo battery is built by too many individual cells (3.7v) joined in series which will provide higher voltages. To raise the flight flying time it is must to use a huge capacity battery. For our work, 11.1v 2200mah battery is used this type of LiPo is made by joining three individual cells which can deliver 2200 milliamp current to the load for one hour. For example, let us take 3300mah battery it will completely drain within one hour when 3300mah load is connected to it. Where the same battery is connected to 1650mah load the battery will drain within two hours as the result says to reduce the load the battery can deliver power for more hour. While selecting a battery for the quadcopter is important to know about discharge rate of it technical says as C-value. The multiple of Discharge Rate and Capacity of the battery will give the maximum current delivered by a battery.

The battery used in our work will have a discharge rate of 35c then the maximum current delivered by battery is approximate 77A it is very important to choose the ESC's and motor which will never cross 77A. Since ESC's of 30A is used in this work, it is well within the safe limit. [10]

An 11.1v LiPo battery gets full charged it will produce 12.6v. While connecting the battery to the charger is careful if mismatch will happen in polarities or overcharging then it is possible to get a burn or violent accident so it is very necessary to keep checking the volts. Proper care should to given when it would not frequently be used.

E. Design methodology of PID controller

The acronym for PID is Proportional Integral and Derivative. This controller will give controlled output if continuous changes happen in the system with the help of the feedback loop. The good PID controller will produce accurate process variable which is used to reduce the oscillation of the system and also increased efficiency. [2] In closed-loop control systems PID tries to meet the exact value which is very near to the desired result by changing the input parameters quadcopter adopt a PID controller to get good stability.[7] The formula for PID is shown in Fig.7. Each PID controller algorithm will have three separate parameters such that Proportional (P) Integral (I) and Derivative (D) values. P indicates the error in the present I indicate the collection of error in past and D indicates the findings of errors in future.

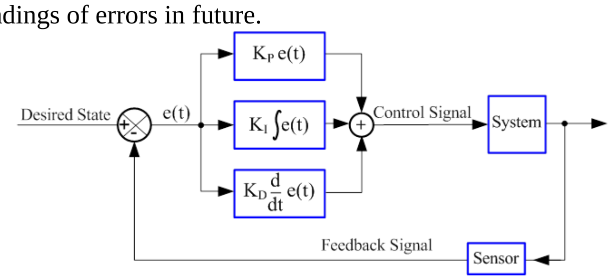

Fig.7. PID controller Block diagram

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Generally, by renovate PID value has the good results upon a quadcopter's behavior.

Proportional Gain coordinate:

The Quadcopter will glide only with Proportional gain without using integral and derivative gain. The proportional gain is determined by measuring the difference between the sensors values (Gyroscopes) from receiver value with a product of Proportional gain with only P controller the quadcopter keep oscillating in the centre position. By making the value as higher would leads to highly sensitive and robust which make the quadcopter to reduce the angular change as much as possible. If it's low the quadcopter has less sensitive and less robust which make the quadcopter to say steady. Major cons in Proportional gain is if it's very high then the quadcopter will get high oscillation and unstable the system.

Integral Gain coordinate:

Integral Gain will help the quadcopter to get an accurate angular position. this gain is very useful to fly a quadcopter in an abnormal environmental condition when the integral gain is minimum then quadcopter will throw over similarly when the integral gain is maximum the quadcopter may be starting to have a less responds and it will lead to effect Proportional gain which makes the quadcopter will have huge oscillation in minimum frequency and unstable.

Derivative Gain coordinate:

Derivative Gain will eliminate damper, overshoots produced by proportional gain and correction the angular movement of the quadcopter.

In the PID adjust process three gains parameters should be calibrated accurately otherwise stabilized of quadcopter will never be achieved as required For example, When Proportional gain values are huge the motor respond stable. If Proportional gain keeps on rising then quadcopter will produce huge oscillations which make the system as unstable. the correctly adjusted PID controller can make the quadcopter can give result when 3-axis force acting on it while flying if the correct adjusted gain is not founded then the quadcopter never fly stably in air. [6]

Initially, PID adjusted should be done by slightly adjusting PID gain value and check the motor responding to the tuned gain then check the quadcopter get back to normal position automatically when any force is acted on their 3-axis. At the same instant, the quadcopter oscillation should be reduced to normal state this work has been done for roll and pitch [2]. All the extreme ends of the quadcopter are tied so that the quadcopter can be stable over at a particular height without any damage. After the results are verified, it is tested in open ground.

VI. Flight Test Results

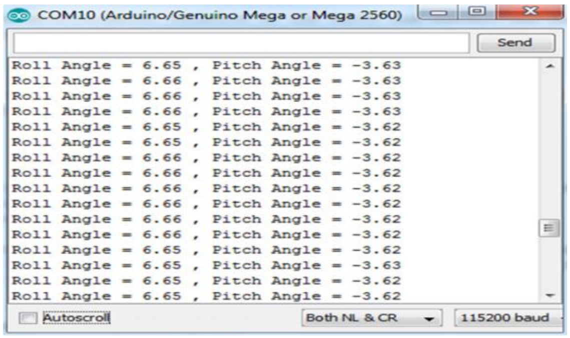

Fig.8. Serial monitor data for Roll and Pitch angle

The Roll and Pitch angle obtained from the MPU6050 is shown in Fig.8. This data is directly taken from the MPU6050 raw value before processing it. The graph is shown in Fig.9. Below show, the response of PID controller for roll and pitch angle value changes frequently when disturbance acting on it.

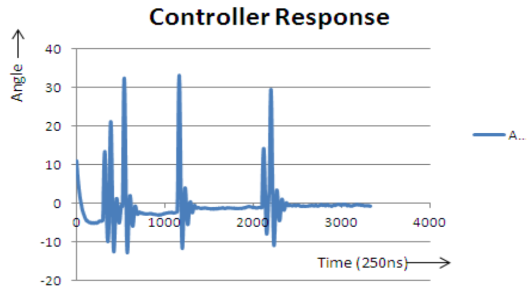

Fig.9. Controller response for Roll and Pitch angle

Fig.10. Shown below is the complete setup quadcopter with controller unit integrated with all the peripherals.

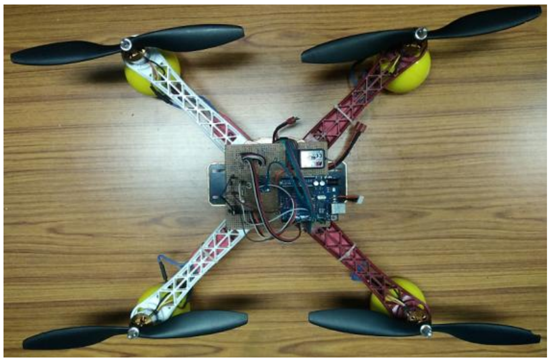

Fig.10. Complete quadcopter setup

VII. Conclusion

A real-time UAV was integrated and tested for its stable performance. All the individual components were integrated, tested, and seen the result for various environmental dynamics. Tuning the parameters was executed in PID controllers to achieve stable flight without any oscillation and good response of the quadcopter achieved.

Currently, the weight of the quadcopter will around 1.685 kilograms, sustain average flight time as 10 minutes, and can be controlled around a range of 320 meters.

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