Basic Multicopter Control with Inertial Sensors

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Abstract- In the world of photography, surveillance of larger areas and military operations, the immediate machines that accommodate the Unmanned Aerial Vehicle (UAV) category are the autonomous aeroplane and helicopter. Helicopters have clear advantages over the aeroplanes. They can be able to hover and land/take off in limited spaces. The quad rotor is a helicopter that has four rotors which are fixed to a certain spin axis. The different spinning directions of the motors balance the torques on their associated axes, therefore eliminating the need for a tail rotor that a normal helicopter requires. As long as all four rotors rotate at the same speed, the quad rotor helicopter essentially hovers, this proving to be a less complex in mechanical structure. Researches are being done to improve the reliability and decrease the size of such vehicles. So, they can be used in Search and Rescue operations, surveillance, inspection, aerial photography and aerial mapping.

I. INTRODUCTION

Quadcopter is a flying vehicle with six degrees of freedom which uses four rotors to push air downwards and to create a thrust force for keeping the quadcopter on the air. The pilot or flight control unit will control the orientation and tile of the multicopter by reading the data from the sensors. Gyro, accelerometer, magnetometer or GPS can be used to sense the tile, orientation and position of the vehicle.

In the quadcopter, flight controller unit (FCU) is the heart of its control system. The (FCU) will control the different motors speeds with its different PWM outputs. The FCU will control the vehicle in the air by taking information from sensors such as barometer, magnetometer, accelerometer, gyro and GPS. Sometime radio remote control is used to control the vehicle. In the actual world the radio remote control is similar to ground control station and the FCU is similar to a pilot. Even when the information from the ground station is cutoff, the FCU can decide himself how the vehicle should be controlled. So we can say that is UAV.

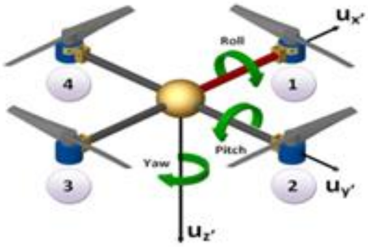


Figure 1. Yaw, pitch and roll rotations

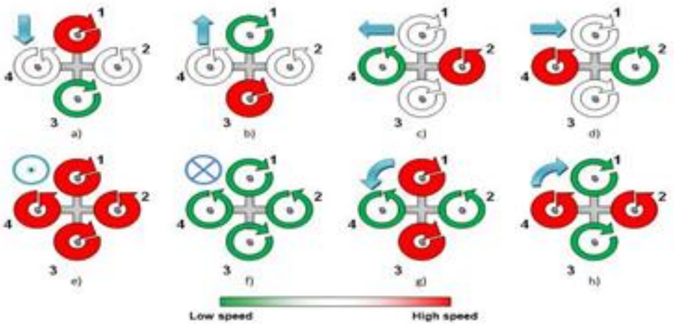


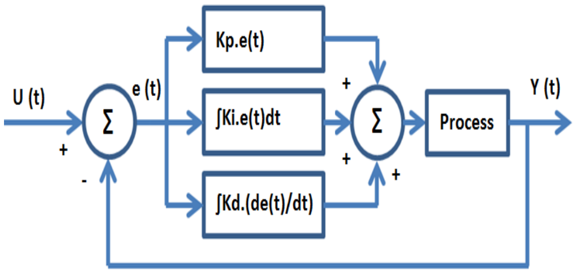
Figure 2. Multicopter's movements

Figure 3. Basic and simple multicopter control system

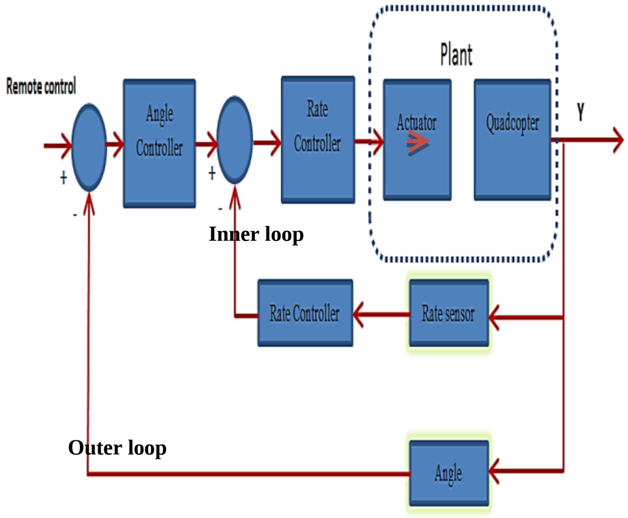
Overview of quadcopter control is described in this paper. In the basic control system of a quadcopter, a FCU, sensors and a radio remote control are included. In this system, if the FCU receives the command from the ground station, it can be able to place the vehicle at the exact position.

II. CONTROL ARCHITECTURE

In designing the control system, control architecture plays as an important role and there are several issues, which have to be considered, such as efficiency, cross-coupling, responsiveness and complexity. There are several control systems. Among them, PID is one of the common used and powerful control systems because of its simplicity and reliability. PID algorithms will try to control the output of a system by minimizing the errors between the desired point and actual point. Proportional, integral and derivative are three terms which make up PID control and they are applied to each axis.



PID Controller



Overview PID Controller structure

There are two PID loops, inner loop and outer loop. The inner loop is for rate correction and the outer loop for angle errors correction. So, the quadcopter will approach to the desired angle by adjusting each rate of every axis.

III. PID TUNING

Applying the PID algorithm may be easy, but the main challenge for PID control is tuning its constants (K_p, K_i, K_d). By tunning the constants we will ensure that the system behaves in a desired manner by reducing the errors as small as possible. There are several methods in which PID can be tuned. They are Ziegler Nichols (Open and Closed loop) method, and Trial and Error method.

Tunning with trial and error method is very simple and easy for anyone and it can be done on the stand or string with the help of GUI before flying. After the PID tuning before flying, it is required to tune the PID controller while flying in the air. By mean of this, the quadcopter will be able to face or response the disturbances in the air.

Rx angle damping 9.5
Rx sensitivity 3

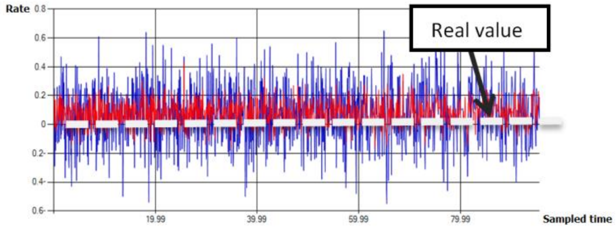
Tuning GUI for user

Testing on the string and the stand

IV. SENSOR FILTERING AND ALTITUDE ESTIMATION

MPU6050 is chosen for sensing angles and rates due to low cost and its low power consumption and in which three axis MEMS accelerometer and gyro contained in a single chip.

Attitude estimation and sensor filtering are also important for a quadcopter because of the vibration effects produced by the great speed of four motors. For this purpose, a variety of sensor effects are used for estimation to get exact attitude and rate of the vehicle. This is called sensors fusion. Sensors fusion is a challenging technical barrier because it must take place in near-real time in order to be useful for stabilization. Hence, some considerations had to be taken into account when looking at various filtering methods to be used for sensor fusion. Simplicity and low computation complexity are the primary concern for choosing the algorithm.

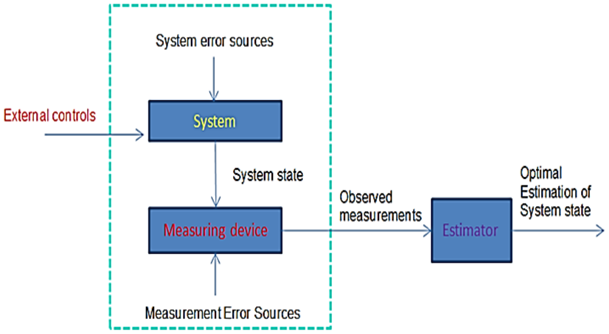


Noise effects due to motor speed

Figure-7 shows the noise produced by the grate speed of motors. The real values of rate should be at zero but it is vibrating between +/-0.6. This will cause difficulties to set D-gain because of its fast response. So, that noise should be removed and smooth before inputting to the PID controller.

The most common attitude estimation algorithms are Extended Kalman Filter, Non-linear and Linear Complementary filter and weighted average Infinite Impulse Response (IIR) filter. Sometime, median filter, low pass filter and high pass filter are also used to remove vibration effects.

V. KALMAN FILTER



Kalman filter

The kalman filter works into two steps by prediction and Correction. From figure, let *p* and *v* be three-dimensional (3-D) position and velocity in earth-fixed frame, q the quaternion, and *b* the gyro bias. Let $R_{eb}(q)$ and $\Omega(q)$ be rotation matrix that converts body-fixed frame to earth-fixed frame and quaternion rates matrix, respectively, as a function of the unit quaternion. Let *a* stand for linear acceleration in body fixed frame and ω is the angular velocity in body-fixed frame. Then, the state equation in discrete time can be written as

$$x_k = \begin{bmatrix} p_k \\ v_k \\ q_k \\ b_k \end{bmatrix} = \begin{bmatrix} v_{k-1} \\ \mathbf{R}_{eb}(q_{k-1}) \cdot a_{k-1} \\ \frac{1}{2}\Omega(q_{k-1}) \cdot \omega_{k-1} \\ w_{b,k-1} \end{bmatrix}. \tag{1}$$

In this equation, the gyro bias *b* is modeled with noise ω_b. The system input *u* consists of measurements of angular velocity ω_{m} and linear acceleration a_m:

$$u_k = \begin{bmatrix} \omega_{m,k} \\ a_{m,k} \end{bmatrix} = \begin{bmatrix} \omega_k - w_{\omega,k} + b_k \\ a_k - w_{a,k} - \mathbf{R}_{eb}^T(q_k)[0\ 0g]^T \end{bmatrix}, \tag{2}$$

Where w_ω and w_a represent noise and g is gravitational acceleration. Substitution of (2) into (1) yields the following nonlinear model:

$$\begin{aligned} x_k &= f(x_{k-1}, u_{k-1}) + w_{k-1} \\ &= \begin{bmatrix} v_{k-1} \\ \mathbf{R}_{eb}(q_{k-1})(a_{m,k-1} + w_{a,k-1}) + [0\ 0g]^T \\ \frac{1}{2}\Omega(q_{k-1})(\omega_{m,k-1} + w_{\omega,k-1} - b_{k-1}) \\ w_{b,k-1} \end{bmatrix}, \end{aligned} \tag{3}$$

Where $W_{k=}[w_{\omega,k}, w_{a,k}, w_{b,k}]^T$ is process noise. The nonlinear measurement model is (omit time index k for notational simplicity).

$$z_k = h(x_k) + v_k = \begin{bmatrix} p \\ v \\ m_b \\ h_b \end{bmatrix} = \begin{bmatrix} p \\ v \\ \mathbf{R}_{eb}^T(q)m_e \\ -P_z \end{bmatrix}, \tag{4}$$

Where m_b is the measurement of the magnetic field of the earth m_e in body frame, h_b is the height measured by the barometric sensor reading P_z, and v_k is the measurement noise. The states are estimated by the standard EKF algorithm and measurements from accelerometers, gyroscopes and magnetometers are fused to estimate the states.

VI. LINEAR COMPLEMENTARY FILTER

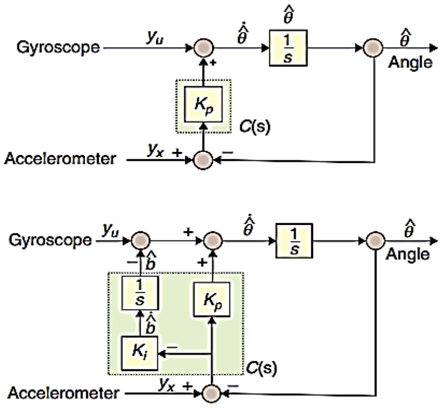
Linear complementary filter on each axis of the accelerometer and gyroscope is shown in Figure-9. It is designed to fuse multiple independent noisy measurements of the same signal that have complementary spectral characteristics. Let y_u be the rate measurement of the angle Θ and y_x the angle measured by accelerometer. The complementary filter to estimate the angle Θ is given by

$$\dot{\hat{\theta}} = y_u + k_p(y_x - \hat{\theta}), \tag{5}$$

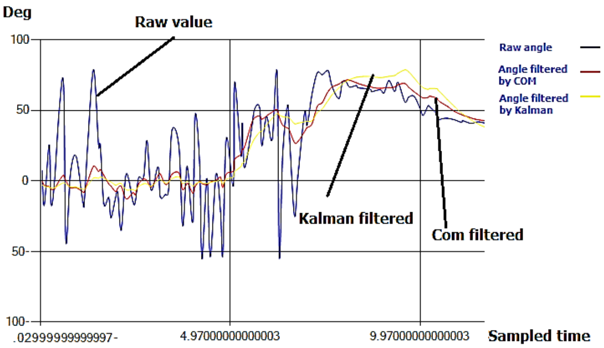
Where $\hat{\Theta}$ represents the estimate of θ and k_p is a gain that determines crossover frequency. This complementary filter assumes that there is no steady-state estimation error. Nevertheless, in practice, the gyro bias changes over time. To compensate for this, an integrator is added to obtain the following:

$$\dot{\hat{\theta}} = y_u - \hat{b} + k_p(y_x - \hat{\theta}), \tag{6}$$

$$\dot{\hat{b}} = -k_I(y_x - \hat{\theta}). \tag{7}$$

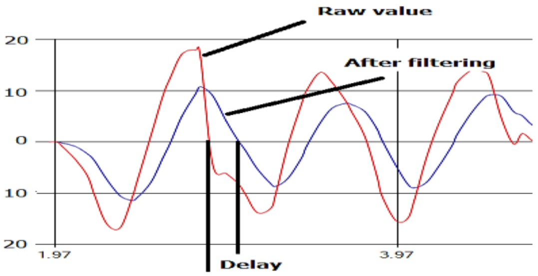


The two type of complementary filter(without bias compensation and with bias compensation)



COM and Kalman filter comparasion graph

By this figure, the output results of complementary filter and kalman filter are similarly. So, complementary filter can also be choosen to reduce computation complexity.



Delay due to filtering process

The next problem for filtering process is its delay. Figure-11 shows the raw value and filtered value. In which the value is smooth but it late with some delay due to its filtering process. So, it is need to be considered to reduce this delay as much as possible. If not the controller will react lately and it will produce lower frequency oscillation and never reach to the setpoint.

VII. PARTS REQUIREMENTS FOR BASIC UAV QUADCOPTER

The basic requirements for a basic quadcopter control system testing are shown in figure-12.

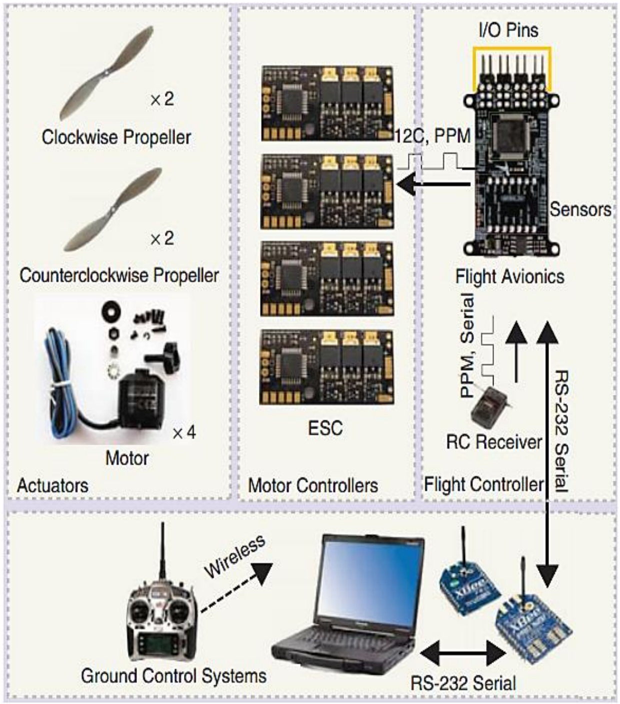
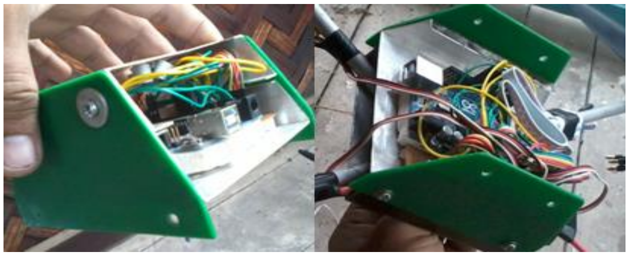


Figure 13. Parts requirements to built a simple multicopter

VIII. QUADCOPTER USING ARDUINO UNO AND MPU6050

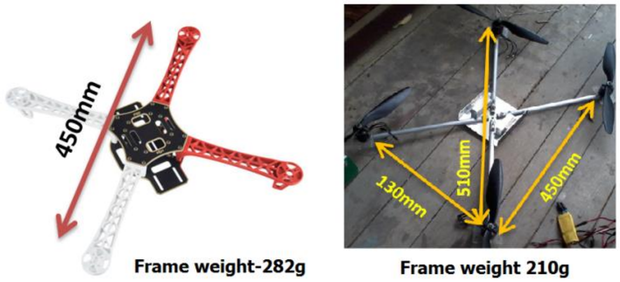
Quadcopter project using MPU6050 sensor and Arduino Uno is shown in figure. This project includes GUI (for PID tunning and real time debugging), quadcopter and Radio control. The users can choice the controller mode (Rate mode or Angle correction mode). At rate mode; the controller will control the quadcopter with only inner loop and at angle correction mode; the controller will control the quadcopter with outer loop and inner loop combination.



Complete controller board

Quadcopter tunning GUI written iny visual basic

FCU assembled on the homemade aluminium and DJI frame



Frame weight-282g

Frame weight 210g

Flame Wheel 450 (F450) and aluminium frame

IX. CONCLUSION

Recently, there has been increasing interest in quadrotor Unmanned Aerial Vehicle. Exciting videos have been published on the Internet by many research groups and have attracted much attention from the public. This journal is proposed the overview of UAV platform and the basic of UAV system, so no GPS and other effective sensors are not included. The effective changes in hardware and software can give high stability and reliability in UAV system.

The stability of quadcopter will depend on the PID Tunning. It is need to be tuned the flight controller with each different body frame. Testing on the stand cannot give the correct PID gain because of its friction on each joint.

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REFERENCES

[1] Control Engineering a practical guide by Manfred Schleicher Fulda (February 2006)

[2] Build your own quadcopter by Hyon Lim, jaemann Park Daewon Lee, and H.J. Kin

[3] RC toys web site, www.rctoys.com., retrieved December 2006.

[4] Integrated Inertial Positioning Systems, Zupt, LLC, http://www.imarnavigation.de/englishside/downl_engl/workengl.htm,retrieved December 2006.

[5] Design of control systems for a quadrotor flight vehicle equipped with inertial sensors

[6] ADXL203EB datasheet, www.analog.com, retrieved December 2006.

[7] The Aeroquad Open Source Project (Available at:
http://www.aeroquad.com)
Arduino Playground - MPU-6050

[8] Draganfly Innovations, Inc. Available at: http://www.draganfly.com

[9] Higgins, W.T. "A Comparison of Complementary and Kalman
Filtering," Aerospace and Electronic Systems, IEEE Transactions on , vol.AES-11, no.3, pp.321-325, May 1975,URL:http://ieeexplore.ieee.org.ezproxy.uky.edu/stamp/stamp.jsp?tp=&arnumber=4101411&isnumber=4101405

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