

TEST PLATFORM, DATA COLLECTION, SYSTEM IDENTIFICATION OF MULTICOPTER VEHICLE

MSc. Taner Mutlu, Prof.Dr. Cengiz Hacizade

ISTANBUL TECHNICAL UNIVERSITY, FACULTY OF AERONAUTICS AND ASTRONAUTICS, ISTANBUL, TURKEY

E-mail: tanermutlu@gmail.com , cingiz@itu.edu.tr

Abstract: Multicopters are widely used in a professional manner today in film industry, military applications etc. These vehicles are easy to build which have mechanical and electrical parts. Also autopilots are being sold to control these vehicles. However, mostly these vehicles are being built and used with little knowledge about the system dynamics, performance and stability. Mostly wrong propeller motor battery combinations are used. And mostly these vehicles are being used by different payloads. Every change in payload changes dynamics and stability of the vehicle. Very little of users are eligible at PID tuning and increasing the stability of multirotor vehicles. We aim to provide a test platform and methodology for system identification and increasing stability of Multirotor Vehicles.

KEYWORDS: MULTIROTOR, SYSTEM IDENTIFICATION, KALMAN FILTER, TEST PLATFORM, MATHEMATICAL MODEL

1. Introduction

In this study real time data collection and system identification of dynamic parameters of a multicopter type robotic vehicle is aimed. A test bed for safe testing of the vehicle and isolation of required degrees of freedom is built. Sensors are mounted and data is transferred to computer real time. The PC is used for development of sensor fusion algorithms, real time parameter estimation and adaptive control algorithm development and visualisation. On computer MATLAB Real Time Windows Target is used. The ultimate aim is to precisely model the multicopter vehicle, and build a robust controller. Sub Parts will be modeled as well as the whole vehicle. Stability analysis of single DOFs and cross coupling will be investigated. Kalman Filter for sensor fusion will be applied[1,5].

2. Design Considerations

Frame: there are many frame types available for multicopter design. The most important parameter of frame is its rigidity which should not let unwanted vibrations to be transferred from motor-props to the sensors. **Tricopter:** this frame type is formed by three arms and three prop-motors and a servo motor to control the tail motor roll angle. Since it is not symmetrical torque balance is obtained by tail servo. They suffer from less than stellar performance and are not suitable for larger sizes. **Quadcopter:** this frame is most common, it is symmetrical and embody the simplest principle of operation for controlling roll, pitch and yaw operation. There are many variations of Quadcopter frames, +, X, Dead Cat, H The X frame is considered best for flight performance and stability since its natural symmetry balances flying forces better. Long endurance multicopters are generally chosen X frame with low RPM high wattage and big size props. It is possible to obtain 60min flight times. Hexacopter and Octocopter are chosen for professional heavy lift tasks such as professional heavy lift cameras. In filming camera vibration is very important and should be omitted. With heavy lifts hexa and octo frames provide more stable less vibration flights. But at a cost of efficiency compared to quadcopters. Also they are more prone to failure since they have more components. It is a possibility with these frames to safely land even with one motor failure. Y6 and X8 frames are double contra rotating prop designs which provide most lift in smaller area, but again at a cost of efficiency. Which is about 20-30%

compared to regular frames. On the contrary, on heavy duty airplanes contra-rotating props have 7% more efficiency. The reason of different results is to be investigated. Maybe it is due to turbulence of downwash of upper propeller in multicopters since they turn slower compared to on airplanes. Its advantage is practical frequent usage due to its smaller size.

Power train(Motor-Prop-Battery): The flight time, take-off weight capacity, dynamic behaviour is mostly related to power train. The multicopter design should fit to the task. For long endurance multicopter lesser arm frame with low RPM high power motors matched with big size propellers and suitable voltage-weight battery should be chosen. Also the propeller pitch angle is chosen smaller. The higher the motor RPM needs to be the lesser is the efficiency. The long endurance designs are less stable with heavier payloads due to big prop sizes. For heavy duty applications a little bit higher RPM high power-to-weight motors are chosen. Not too high as airplane, since they use smaller high pitch propellers with high RPM motors. Frame is generally chosen Hexa or Octo for stability and chance of survival on one motor failure. If power to weight ratio high enough, autopilot will be able to safely control the multicopter, and save the expensive heavy payload.

Balance: The multicopter is an aerial platform and symmetry and balance is very important for stability of AC and long life of components and AC itself. The components should be so well located that the c.o.g of AC should be close to the geometrical center point of AC where Autopilot Inertial sensors are located. The motor and props should be well balanced, if props are not well balanced vibrations will occur and wear out the motors and props, which eventually will cause prop breakout or motor breakout. Also unbalanced motor or prop will cause vibrations on the Inertial sensors. The more vibrations on the IMU the more integration error becomes. Which will cause positioning errors at the absence of GPS. Vibration dampeners should be installed under the IMU sensors. The balancing of prop-motors is still necessary to prevent prop-motor breakouts[2].



Picture 1: X type frame quadcopter picture



Picture 3: 3DOF Test platform for quadcopter, multicopter and helicopter around ball bearing fixture

3. Tests and Data Collection

Test apparatus data collection and system identification has been designed. One test bed is single axis Degree of Freedom ball bearing table for one axis, two axis and three axis dynamic behaviour investigation of multicopter. In this test bed yaw, torque, pilot stick input to roll, and pilot stick input to pitch response can be investigated and safely recorded for system identification.

Second test bed is power-train test bed where the the whole components of the power train(Propeller-Motor-Motor Driver-Battery-Pilot input) can be tested at once. This test bed is good for finding the most efficient propeller-motor-battery combination, testing the motor driver performance, and collecting data for power-train transfer function system identification mathematical model.



Picture 2: Power train test platform

Power train system is tested using a variable power supply, precision scale, motor, propeller and motor driver with variable PWM input. Lift, Voltage, PWM Percentage, RPM, Current Drawn is measured. Also the effect of imbalance of propellers and motors due to RPM can be measured by adding an accelerometer to the test bench. Power train vibration reduction is problem which should be absolutely minimized. In table 1 the power train system measurements can be seen, most the measurements are omitted because of scarce space. 5 different motor, 10 different propellers, two voltage values are simultaneously measured.

4. Sensors and Modelling

Magnetic Sensor Model: The MEMs sensor HMC5883 is used for measurement of Magnetic Heading

IMU Model: The MEMs IMU is MPU6050 , in Simulink IMU model natural frequency, noise, bias, and damping parameters can be simulated.

Power-Train Model: Power train model is considered as combination of Battery-Motor Driver-Motor-Propeller. The input is a Pulse Width Modulation (PWM) signal from autopilot which is 1-2ms interval 50Hz signal(some autopilots may have shorter control loops.)

Earth magnetic model: The earth magnetic deviations are modelled using simulink. The mathematical model accepts date and GPS coordinates and gives the magnetic heading deviation. Earth magnetic model is constructed using USGS measurement database[3].

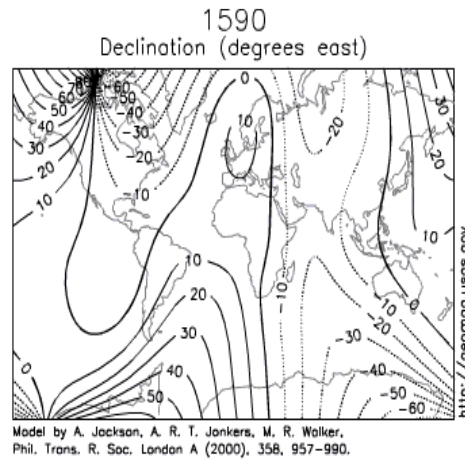


Figure 1 : Earth Magnetic Deviation Model.

Earth magnetic model shows us that the magnetic deviation is +20degrees.

GPS model error is +10m. GPS error is simulated using Zero-Order Gauss Noise.

The generalized coordinates for a rotorcraft are:

$$Q=(x,y,z,\theta,\phi,\psi)$$

Where (x, y, z) denote the position of the center of mass of the rotorcraft relative to the frame, and (θ, φ, ψ) are the three Euler angles which represent the orientation of the craft.

After calculations following are the non-linear equations of motion[1]:

$$\begin{aligned}
 m\ddot{x} &= -u\sin\theta \\
 m\ddot{y} &= u\cos\theta\sin\varphi \\
 m\ddot{z} &= u\cos\theta\cos\varphi - mg \\
 \dot{\varphi} &= \tilde{\tau}_\varphi \\
 \dot{\theta} &= \tilde{\tau}_\theta \\
 \dot{\psi} &= \tilde{\tau}_\psi
 \end{aligned}$$

The first control input is u which is defined as follows:

$$\begin{aligned}
 u &= f_1 + f_2 + f_3 + f_4 \\
 f_i &= k\omega^2
 \end{aligned}$$

The desired outputs for each individual motor can be calculated from the following equation:

$$\begin{bmatrix} u \\ \tilde{\tau}_\theta \\ \tilde{\tau}_\varphi \\ \tilde{\tau}_\psi \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ -c & c & -c & c \\ 0 & -l & 0 & l \\ -l & 0 & l & 0 \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{bmatrix}$$

where c is the torque produced by each motor about the ψ axis and l is the moment arm to each motor[4].

5. System Identification

System identification is the process of measuring the inputs and outputs of a dynamical system and obtaining the mathematical model of system. For this purpose precise measurement and correct test system setup is very important. The control inputs scenarios should be carefully selected so as much as bandwidth of the system is considered. Inputs can

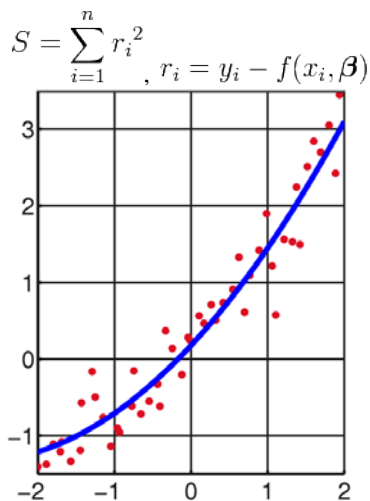


Figure 2 : Curve fitting with quadratic function

6. Precautions and means for resolving the problem

Testing the device on air is a time consuming and costly procedure. For overcoming this problem a 3DOF test platform is built. Any axis can be limited to individually test the vehicle while collecting data real time.

7. Simulation

Sensors are modelled and simulated using MATLAB Simulink software. In simulation Earth magnetic model, IMU, GPS are modelled and simulated. Also Senseo integration with Kalman Filter is realized. The GPS error is reduces from 10m to 1m.

8. Conclusion

The dynamics and behaviour of a multirotor vehicle is investigated using a test platform both for complete vehicle and single actuator part only. When modelling not only the vehicle but sub components are also being modeled. Motor-Prop-Battery power train is modeled. Single axis control and output is modelled. Sensor behaviour is investigated and modeled. There are many papers focused on multirotors investigating different aspects. Many investigate mathematical model generally, however the sub parts and vibration effects of sub parts locally and overall are not well investigated. Many research papers investigate a preconfigured multicopter, however here we state that multicopter should be precisely designed according to payload and flight performance parameters required.

9. Literature

[1] <http://diydrones.com/>
 [1] Michael A. Demetriou , Design Optimization of a Quad-Rotor Capable of Autonomous Flight, WORCESTER POLYTECHNIC INSTITUTE
 [3] Taner Mutlu, Chinghiz Hajiyev, Modelling And Integration Of Navigation Sensors, Xsometro, Bueonos Aires, 2013
 [4] <http://geomag.usgs.gov/>
 [5] R. M. Rogers, "Applied Mathematics in Integrated Nnavigation Systems," American Institute of Aeronautics and Astronautics, 2000.

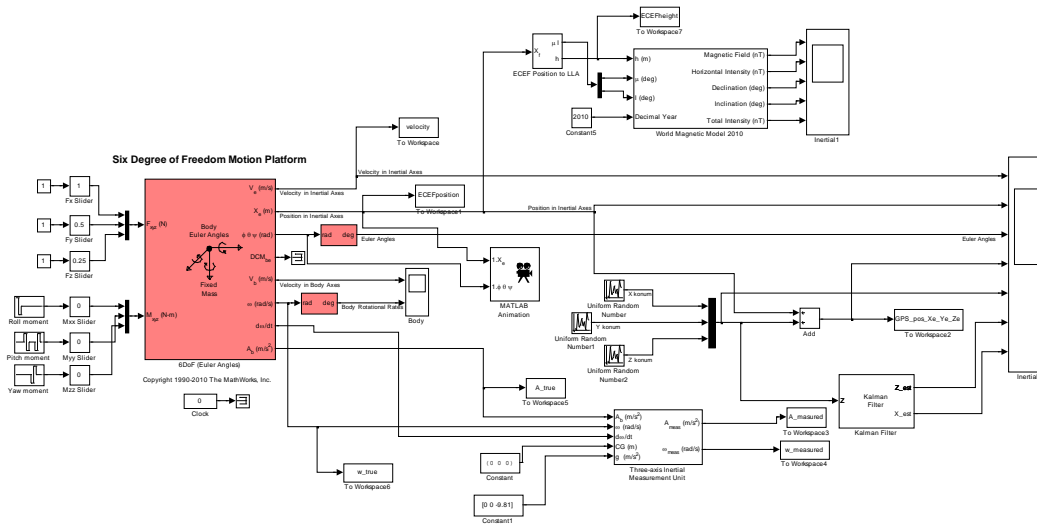


Figure 3 : Sensor Simulation of GPS, Magnetometer, Earth Magnetic Model and IMU

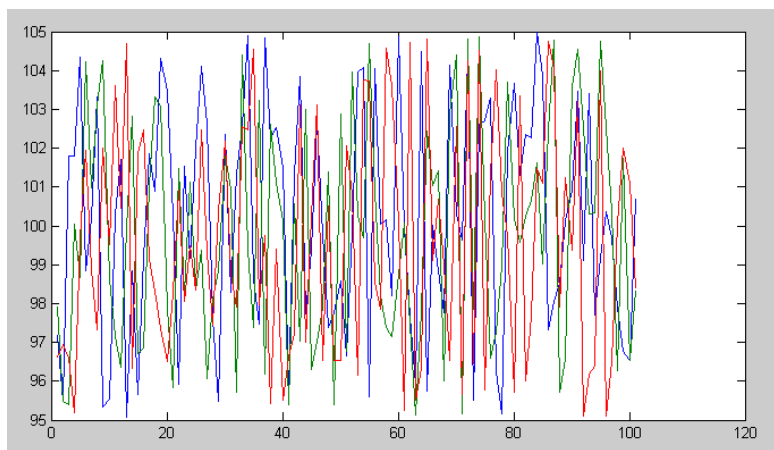


Figure 4 : GPS simulation results(+/-10m)

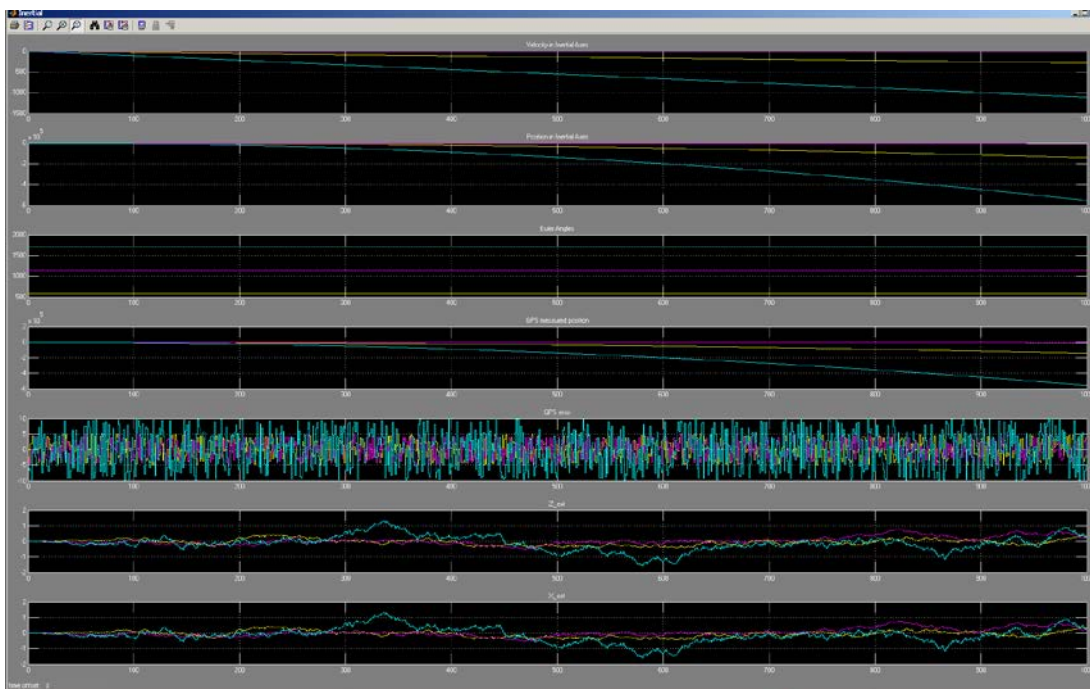


Figure 5: Inertial Axis velocity, position, GPS measurements, GPS real errors, and Kalman Filter estimation outputs are shown.

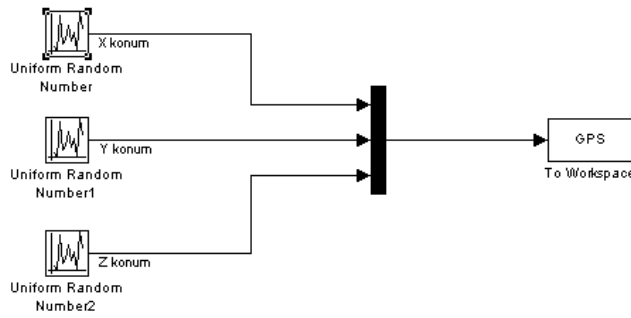


Figure 6 : GPS static position simulation

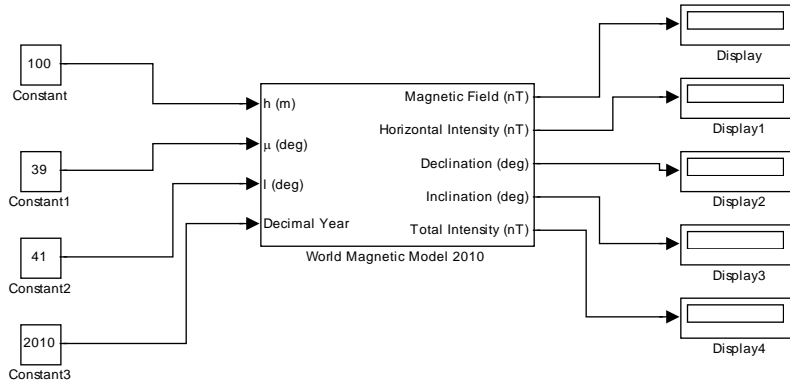


Figure 7 : Earth magnetic model simulation

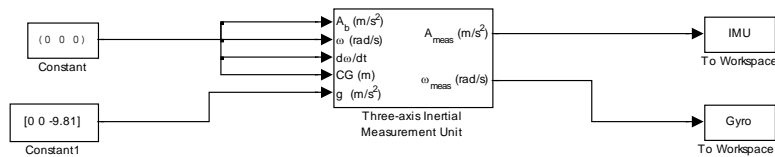


Figure 8 : IMU 6DOF simulation model

Table 1: Power train measurements

	Motor	Motor Weight(gr)	Propeller	Propeller Weight	Battery Voltage	Battery Weight(gr)	PWM(%)	Current(A)	Lift(gr)	Lift/Power Ratio
1	Sunnysky X4112	150	16x5	20	14.8	885	-	5	720	-
1	Sunnysky X4112	150	16x5	20	22.2	1300	-	5	920	-
1	Sunnysky X4112	150	17x8	70	22.2	1300	-	5	800	-
1	Sunnysky X4112	150	15x8	46	22.2	1300	-	5	900	-
1	Sunnysky X4112	150	15x4	22	22.2	1300	-	5	600	-
2	Multistar 390KV	102	9x6	16	14.8	885	50	1,78	164	-
2	Multistar 390KV	102	1238	20	14.8	885	50	1	156	-
2	Multistar 390KV	102	1238	20	22.2	1300	50	1	206	-
2	Multistar 390KV	102	9x6	16	22.2	1300	50	1	146	-
2	Multistar 390KV	102	17x8	70	22.2	1300	50	STOP	-	-
2	Multistar 390KV	102	15x8	46	22.2	1300	50	STOP	-	-