

# Blackbox Modelling of a 6 Rotor Helicopter

Balya Bin Darohini, Muhammad Izzat Faez Bin Yusuf, M. F. Abas, N. Md. Saad,  
Dwi Pebrianti, M. Z. Ibrahim

*Faculty of Electrical and Electronics Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang  
mfadhil@ump.edu.my*

**Abstract**—Aerial robotics have received a considerable interest in both private builders and research laboratories for several years. In this respect, modeling is needed in the first step of developing aerial robotics or multi-rotor UAV and there are various methods that can be used for modeling. In this paper, the authors discussed and compared two types of blackbox modeling method that is the Continuous State Space using PEM method and the commonly used Second Order Underdamped System with Delay process model. Based on a comparison analysis of the two methods drawn from experimental data, it was found that the Second Order Underdamped System with Delay Modeling gives better similarity for a hexarotor pitch angle model. In contrast, the Continuous State Space model using PEM method in Polynomial gives better similarity to the hexarotor roll angle model. Finally, both tested methods deliver similar similarity for hexarotor yaw angle model.

**Index Terms**—Blackbox; Hexarotor; Polynomial Model; Second Order System.

## I. INTRODUCTION

Aerial robotics have received a considerable interest in both private builders and research laboratories for several years. This interest is motivated by recent technological advances that make it possible to design efficient systems endowed with real autonomous navigation capabilities with no prohibitive costs. Unlike to terrestrial mobile robots for which it is often possible to be limited to a kinematic model, the control aerial robots require knowledge of a dynamic model. This is due to the effects of gravity and aerodynamic forces. These systems, for which the number of control inputs is less than the number of degrees of freedom, are expressed by under-actuated. The control mechanism usually provides one or two control inputs for the dynamics of translation and two or three control inputs for the rotational dynamics. The modeling of an autonomous helicopter has been assessed in numerous articles and journals directly and indirectly.

Oualid Araar et al. in their paper [1] modeled their quadrotor (four rotors autonomous helicopter) using a mathematical modeling. The authors found that the overall equation governing the model is the drag and lift factor, in which the trust factor is then identified using experimental data. Based on the experimental data, it is found that even if all of the four motors are identical, the PWM to speed is not similar to the motors. Thus, the controller which is built upon the model is influenced by the asymmetry of the PWM to speed graph.

Wojciech Giernacki et al. in their paper [2] use a black box modeling for estimating multi-rotor motor-rotor system. The input and output experimental data were inputted into the MATLAB System Identification Toolbox. The system output is the first-order model with pure time delay. This model is then used to design a Coefficient Diagram Method (CDM)

and PID pole placement control with anti-windup compensation.

Similar to paper [2], Przemysław Gasior et al. in their paper [3] used experimental data to model their X8 configuration multi-rotor aerial system. The experimental data is fed into an Open Curve Fitting Tool and Fuzzy Modeling using Takagi-Sugeno Interface in MATLAB. Results show that the thrust estimated values are satisfactory and very similar for each approach.

Karima Benzaid et al. in the paper [4] presents a generalized dynamic modeling of a multi-rotor aerial system. The multi-rotor was first mathematically modeled to obtain a non-linear model. Then, the model is generalized for N numbers of ‘+’ and ‘X’ configuration multi-rotor aerial vehicles. The results show that the generalized model is validated. Besides, the designed PID and integral backstepping control, the performance of 3D trajectory tracking of quadrotor, hexarotor and octotoror is considered good.

Similar to Karima Benzaid, Jae-Gyun Han et al. in paper [5] uses mathematical modeling in modeling their hexarotor aerial vehicle. By implementing PD controller on the model, the hexarotor simulation results were found good with minor fluctuation in the roll and pitch control.

Dafizal Derawi et al. in paper [6] modeled and designed a controller for hexarotor. The mathematical modeling is similar to Karima Benzaid et al. and Jae-Gyun Han et al. although it focused specifically on hexarotor. The model is then controlled using PID controller. The outdoor test result shows a good performance.

In this paper, the author will discuss a comparison study of black box modeling using two methods. The first was an underdamped second order system with delay process model, while the second was continuous State Space model using PEM method in Polynomial Modeling.

## II. METHODOLOGY

The data acquisition setup for a hexarotor can be seen in Figure 1. A Radiolink AT9 Transmitter was used to control the hexacopter, in which the hexacopter was expected to capture the input signal from the radiolink and the output roll, pitch, yaw and throttle. The data was then downloaded to the computer.

The data was collected when the hexarotor was flying in roll, pitch, yaw and throttle condition. Every data was collected for 4 set per condition. 4 set for roll, 4 set for pitch, 4 set for yaw, and 4 set for throttle. Therefore, the total set of data for all conditions to be collected was 16 sets of data. Each set of data was collected by flying the hexarotor for 5 minutes according to the desired condition to get the required

data. For example, to collect the data for a roll set, the hexarotor will be flying in the left and right movement repeatedly for 5 minutes, as depicted in Figure 2.

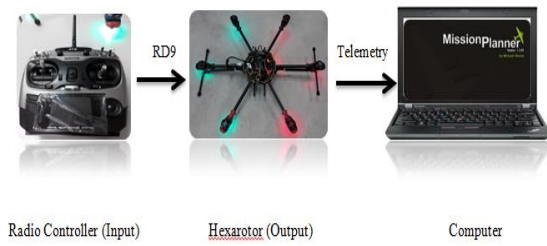


Figure 1: Data collection setup



Figure 2: Hexarotor flying in sinewave form for 5 minutes

After the hexarotor was flown for 5 minutes, the data was stored directly onto the hexarotor. This data was then downloaded from the mission planner software. The mission planner software was used to collect the data from Arducopter Autopilot APM by using telemetry transmitter or by USB data cable. The data received was entered into the log data in the mission planner program. Then, the data were downloaded and created in the file MATLAB. Figure 3 shows the sample of the output data. As can be seen in Figure 3, there are 3 conditions that include the Up condition (a condition where the hexarotor is initially flown to a preset height), Flying Condition (hexarotor is flown from left to right) and Down Condition (the hexarotor is landed). Only the flying condition data were used for modeling.

The modeling was done by using MATLAB's System Identification Toolbox. Two methods of black box identification were used. The first was an underdamped second order system with delay process model, and the second was continuous Continuous State Space model using PEM method in Polynomial.

### III. RESULT AND DISCUSSION

The experimental data have been acquired and inputted into MATLAB's identification toolbox. Two blackbox methods modeling used were the Second Order Underdamped System with Delay process model and the Continuous State Space model using PEM method in Polynomial. Table 1, 2 and 3 show the model output for the pitch, roll and yaw respectively.

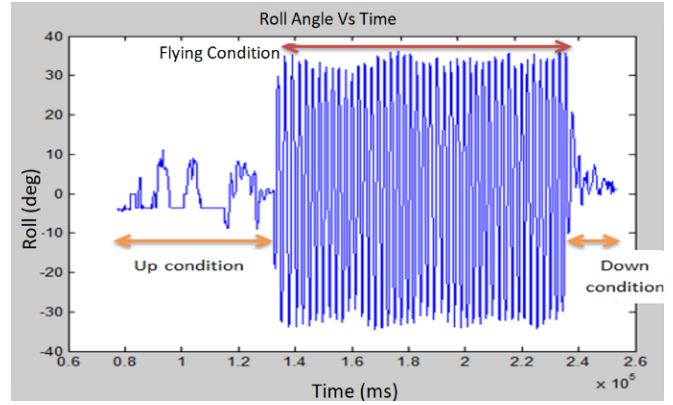


Figure 3: Sample data

Table 1  
Pitch Model

No.	Modelling Type	Model Output
1	Second Order Underdamped System with Delay	$G(s) = \frac{0.9555}{0.0066s^2 + 0.1438s + 1} \times e^{-0.018s}$
2	Continuous State Space Model Using PEM Method	$\frac{dx}{dt} = Ax(t) + Bu(t)$ $y(t) = Cx(t)$

Matrix A, B and C are defined as follow.

$$A = \begin{bmatrix} -1.34 & -1.5 & -2.06 & -0.26 & 0.03 & 0.02 & 3.83 \\ 2.01 & -1.35 & 0.57 & 0.59 & -0.43 & 0.61 & -0.50 \\ 1.16 & -0.06 & -1.81 & -4.23 & -0.20 & -3.70 & 0.26 \\ -0.32 & 0.59 & 2.52 & -2.01 & 6.53 & -0.74 & 5.51 \\ -0.66 & -0.43 & 0.62 & -3.50 & -1.80 & 10.27 & -1.10 \\ -0.41 & 0.43 & 0.15 & -0.39 & -3.22 & -1.85 & 16.80 \\ -0.19 & 0.59 & -0.25 & -0.01 & -0.94 & -2.61 & -3.18 \end{bmatrix}$$

$$B = \begin{bmatrix} -0.61 \\ 0.53 \\ -0.39 \\ -0.77 \\ 0.46 \\ 0.52 \\ -0.02 \end{bmatrix}$$

$$C = [-3.33 \quad 2.65 \quad -1.08 \quad -2.46 \quad 1.55 \quad -3.82 \quad 2.91]$$

Table 2  
Roll Model

No.	Modelling Type	Model Output
1	Second Order Underdamped System with Delay	$G(s) = \frac{0.8289}{0.0056s^2 + 0.5014s + 1} \times e^{-0.017s}$
2	Continuous State Space Model Using PEM Method	$\frac{dx}{dt} = Ax(t) + Bu(t) + Ke(t)$ $y(t) = Cx(t)$

Matrix A, B, K and C are defined as follow.

$$A = \begin{bmatrix} -1.73 & 3.99 & 5.63 & -2.96 \\ -9.58 & -2.34 & -9.85 & 4.61 \\ -12.45 & -1.55 & -14.41 & 12.51 \\ -2.70 & -1.15 & -6.61 & 0.06 \end{bmatrix}, B = \begin{bmatrix} -0.06 \\ 0.27 \\ 0.35 \\ 0.12 \end{bmatrix}$$

$$K = \begin{bmatrix} 0.18 \\ 0.37 \\ -0.07 \\ -0.09 \end{bmatrix}, C = [54.66 \quad 8.45 \quad 1.19 \quad 0.06]$$

Table 3  
Yaw Model

No.	Modelling Type	Model Output
1	Second Order Underdamped System with Delay	$G(s) = \frac{0.9513}{0.0028s^2 + 0.0651s + 1} \times e^{-0.026s}$
2	Continuous State Space Model Using PEM Method	$\frac{dx}{dt} = Ax(t) + Bu(t)$ $y(t) = Cx(t)$

Matrix A, B and C are defined as follow:

$$A = \begin{bmatrix} -7.49 & -5.99 & 9.261 & -1.90 \\ 7.11 & -11.08 & 0.83 & -2.65 \\ -5.36 & 0.04 & -6.93 & 12.02 \\ 2.83 & 0.36 & -1.38 & -12.10 \end{bmatrix}, B = \begin{bmatrix} -6.81 \\ 3.60 \\ -1.50 \\ 1.76 \end{bmatrix}$$

$$C = [-2.22 \quad -3.39 \quad -3.03 \quad -5.01]$$

An experimental input is fed into both of the model output from the Second Order Underdamped System with Delay and Continuous State Space Model using PEM method for each channel. The output result was compared with the measured output. Figure 4, 5 and 6 show the comparison between the three outputs for pitch, roll and yaw channel.

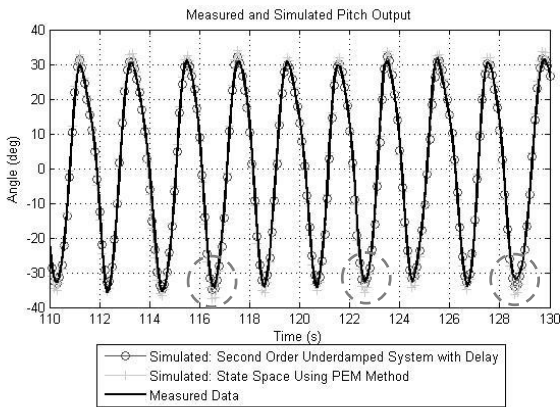


Figure 4: Measured and Simulated Pitch Output

Based on Figure 4, the three outputs waveform show similar result with minor overshoot (circled), as can be seen at  $t=117s$ ,  $t=123s$  and  $t=129s$ . Based on MATLAB identification toolbox output comparison, the pitch model based on Continuous State Space using PEM method delivers 89.5% similarity with the measured data. For the Second Order Underdamped System with Delay, the model output delivers 2% more similarity than that of the previous method, which results in 91.5%. Based on this result, the pitch model using Second Order Underdamped System with Delay gives better similarity.

Based on Figure 5, the Continuous State Space Using PEM Method results in a good similarity to the measured data. Unfortunately, the Second Order Underdamped System with Delay output results poorly at the sharp movement (circled), which can be seen clearly at  $t=215s$ ,  $t=231s$ ,  $t=241s$  and  $t=247s$ . Based on MATLAB identification toolbox output comparison, the pitch model based on Continuous State Space using PEM method delivers 90.3% similarity with the measured data. For the Second Order Underdamped System with Delay, the model output delivers 30.9% less similarity than that of the previous method which results in 59.4%. Based on this result, the pitch model using the

Continuous State Space using PEM method gives better similarity.

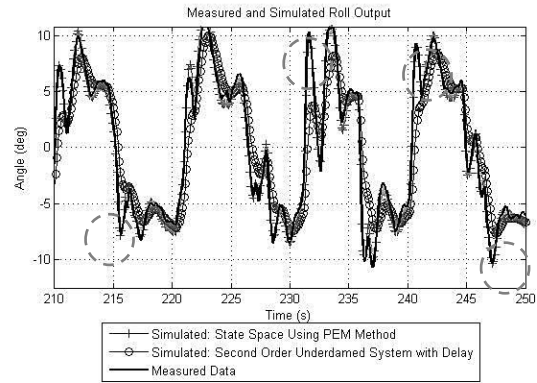


Figure 5: Measured and Simulated Roll Output

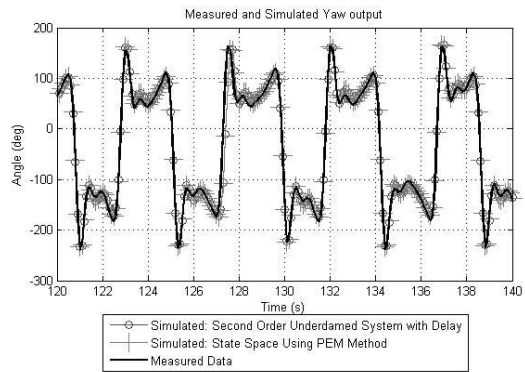


Figure 6: Measured and Simulated Yaw Output

With reference to Figure 5, both the Continuous State Space Using PEM Method and the Second Order Underdamped System with Delay Modeling resulted in a good similarity to the measured data. There is no clear indication that any of the method's outputs have deviated from the measured data. Based on MATLAB identification toolbox output comparison, the yaw model based on the Continuous State Space using PEM method and the Second Order Underdamped System with Delay delivers similar similarity with the measured data, which result in 87.2% similarity.

#### IV. CONCLUSION

Modeling of a hexarotor's attitude has been established via two approaches. The first approach was by using a Second Order Underdamped System with Delay and the second approach is using Continuous State Space PEM method.

For the pitch angle, modeling the channel using Second Order Underdamped System with Delay produces a better result. However, for the roll angle, Continuous State Space PEM method produces a better result. For the yaw angle, both simulated model give equal results.

A precise linear modelling using blackbox method needs to be done using multiple techniques. The best result will be used for the final modeling, although there is no one method that fits all.

Future testing is necessary for other linear modeling using blackbox methods, such as non-linear ARX, neural-network and others.

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