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STUDY OF FIXED WING AIRCRAFT DYNAMICS USING SYSTEM IDENTIFICATION APPROACH

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ABSTRACT

This research work presents the study of fixed wing aircraft dynamics using system identification approach. System Identification is one of the reverse engineering approaches to estimate system dynamics from its measured input and output data's. Here the research papers discuss the data generation method from custom built software, hardware and dynamics estimation of a fixed wing unmanned aerial vehicle. The frequency domain system identification methods are an important aspect of flight control System design and its autopilot tuning. It helps to allows validation of simulated system models, optimization of existing control systems and flight handling qualities. Here Hammerstein-Wiener model is used to make fit the system measured and simulated value by adjusting its pole zero configuration. Finally, transfer functions of the system are estimated from its input and output values and its results are discussed.

Keywords: System Identification, Fixed Wing Aircraft Dynamics, Flight Control System Design.

I. INTRODUCTION

Now a day's one of the most important and interesting topic among the research community is the application of the unmanned aerial vehicle. The operation and usage of the unmanned aerial vehicle has increased because of its unique advantages. Some of the applications of unmanned aerial vehicles are fire and rescue, disaster management, surveillance, oil and refinery pipeline monitoring, Structural inspection and crowd monitoring etc [1, 2]. The unmanned aerial vehicle have an important role where human begin could not been enter (nuclear disaster, deep terrain etc.).Because of the advantages, UAV are used in various applications. There are different types of UAV configurations are available in the world, name as fixed wing, rotary wing and flapping wing. Each configuration has its own advantages and own application. Here the paper presents dynamics of the fixed wing unmanned aerial vehicle using system identification approach.

Figure 1 Shows the Configuration of the fixed wing unmanned aerial vehicle. The aircraft dynamics is classified into longitudinal dynamics and lateral dynamics. The longitudinal dynamics includes composed by X-force, Z-force and pitching moment equations and the lateral dynamics includes Y-force and yawing and rolling moments equations. The attitude of the vehicle can be controlled by its control surfaces. The pitch of the aircraft can be controlled by elevator, yaw of the aircraft can be controlled by rudder and roll of the aircraft can be controlled by aileron. For the input and output data generation purpose we are using a Sky Scout UAV having a wing span of about 1366mm, 900 grams weight (without payload) with a custom built data logger system.System identification is a methodology for building mathematical model of dynamic system using measurements of the system's input and output, essentially by adjusting parameters within a given model until its output coincides with the measured output.

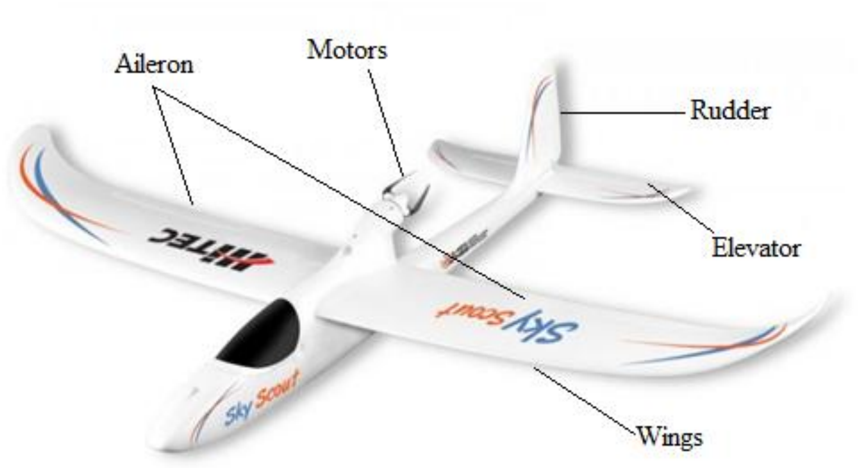

Fig 1.Configuration of the Fixed Wing Unmanned Aerial Vehicle

II. SYSTEM IDENTIFICATION

System identification provides an accurate, rapid, and reliable approach for defining design specifications and for validating aircraft flight performance for highly-augmented flight-control systems [3,4].The dynamics of the system can be estimated by using either parametric or nonparametric identification methods. The study presents the first steps towards the development of autopilots for fixed wing unmanned Aerial vehicle. Utilizing data collected from real-time human-controlled test flight, the standard identification approaches were applied to obtain a MIMO linear model for fixed wing UAV configuration [5].

III. FREQUENCY DOMAIN SYSTEM IDENTIFICATION

The frequency domain System identification process is comprised of two steps. The first identification steps extract frequency responses using spectral quantities from the measured input and output data's [6]. in this paper, control surface deflection recorded by the flight control computer is consider as input and the gyros and accelerometer reading are taken as output's.

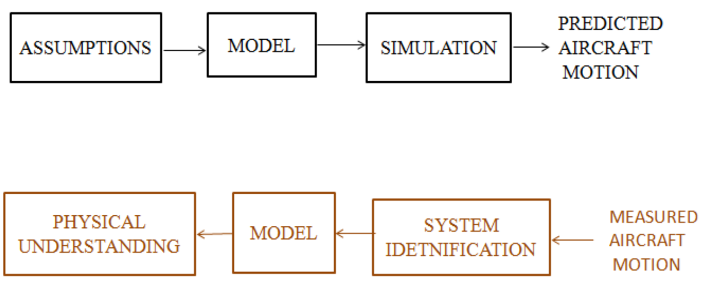

Fig 2. Block Diagram of System Identification

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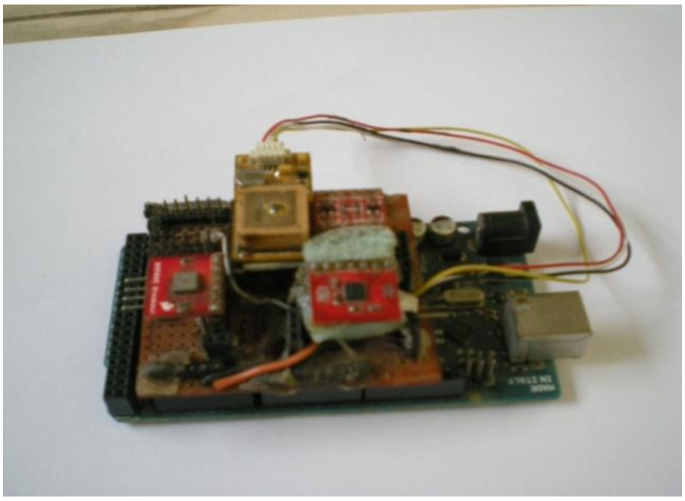
Parametric Identification Methods are techniques to estimate parameters in given model structures. The numerical values of the parameters are finding in an iterative manner that gives the best agreement between the estimated output and the measured output. Nonparametric Identification Methods are techniques to estimate system behavior without any model structure. Typical nonparametric methods include Correlation analysis, which estimates a system's impulse and step response. The spectral analysis is useful in frequency response estimation [7].



Fig,3. Hardware Setup for Data Logging System

Figure 3 shows the custom built hardware setup for the data logging system. It consists of three axis accelerometer, 3-axis gyroscope, 3-axis magnetometer, GPS (optional) and X-bee wireless radio. The heart of the data logging system is atmega 2560 microcontroller. It is a 32 bit processor, having 54 digital input/output ports16 analog input ports, 4 UARTS and I2C ports operate at a speed of about 16MHZ. The input and output data's generated during various phases of flight conditions are recorded on the ground control station trough X-Bee radio operates at a frequency of 2.4 GHZ. Figure 4 shows the software data logging system.

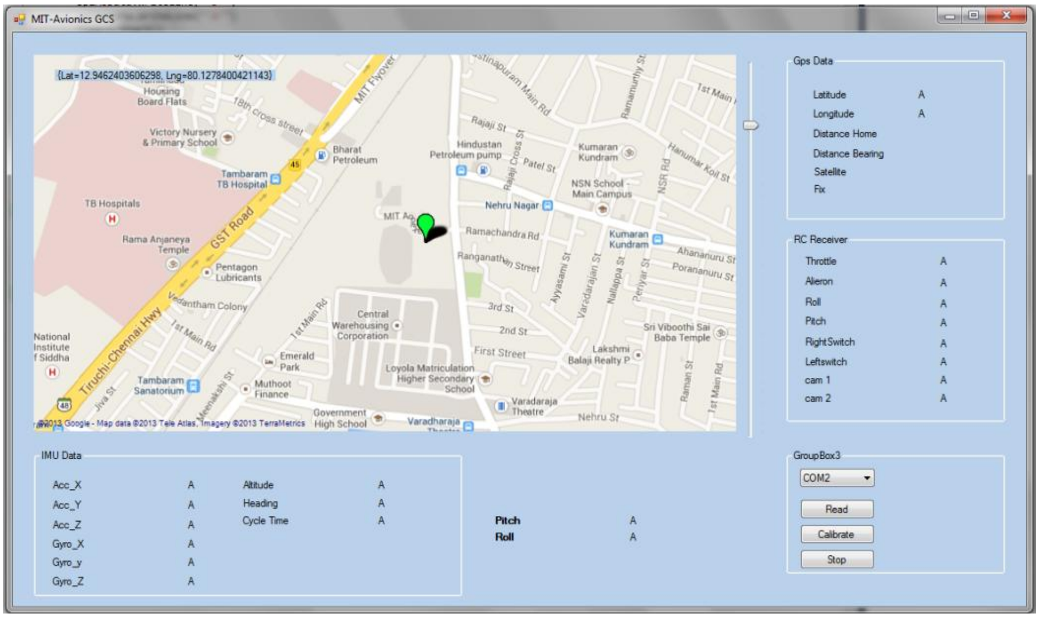


Fig 4 Software Data Logging Panel

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IV. NON LINEAR SYSTEM IDENTIFICATION PROCESS

Dynamic models in System Identification are mathematical relationships between the system's inputs u(t) and outputs y(t).

$$y(t) = f[u(t - 1), y(t - 1), u(t - 2), y(t - 2), . . .] \qquad (1)$$

Such a model is nonlinear if the function f is a nonlinear function. f may represent arbitrary nonlinearities.

V. HAMMERSTEIN WIENER MODEL

Hammerstein-Wiener model is one of the models in the system identification approach. It is a black-box model structure provides a flexible parameterization for nonlinear models. For example, you might estimate a linear model and try to improve its fidelity by adding an input or output nonlinearity to this model. The developed model can be tuned by its input and output nonlinearity functions.

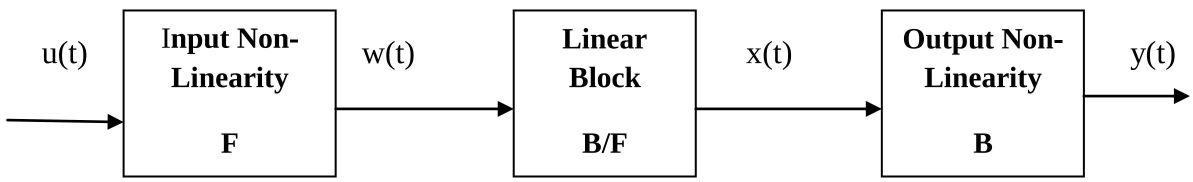

Fig 5 Hammerstein Wiener Model

Here the taken 1500 data samples of elevator, aileron, rudder angle deflection (u1, u2, u3) as inputs and coresponding pitch, roll, yaw angle (y1, y2, y3) during the cruise mode of the unmanned aerial vehicle. The Fig 2 shows adjusting parameters of poles and zeros configuration of given model to make the output coincides with measured input/output values. Figure 6 shows the configuration of the Hammerstein Wiener Model.

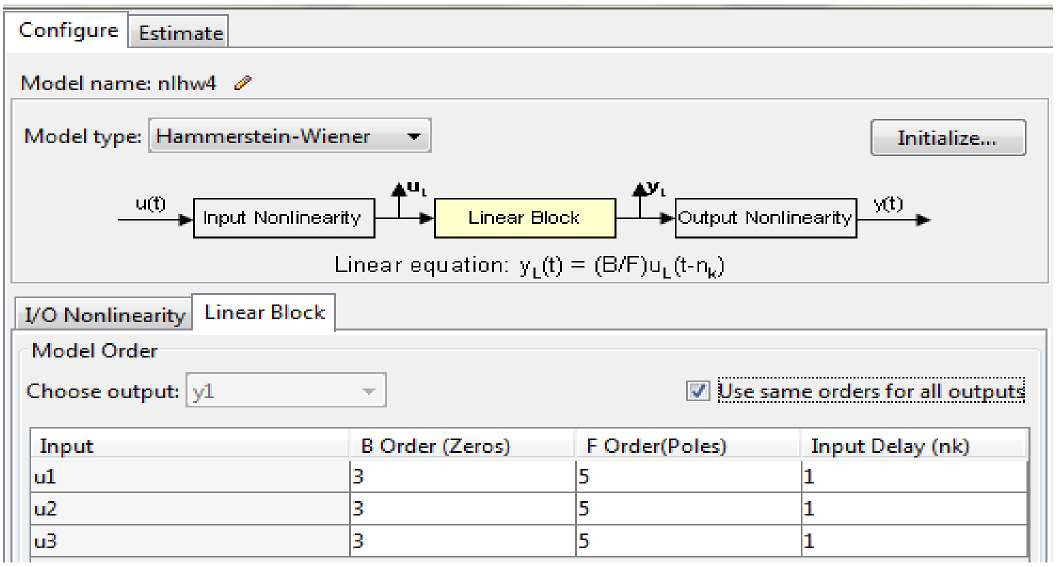

Fig 6 Configuration of Hammerstein Wiener Model

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VI. RESULTS AND ANALYSIS

The input and output non linearity of linear system has been estimated. The progressed trace in figure 7 indicates the modeled output in green line and measured output in black line. The system could achieve about 75.17 % best fits by its better pole-zero estimates.

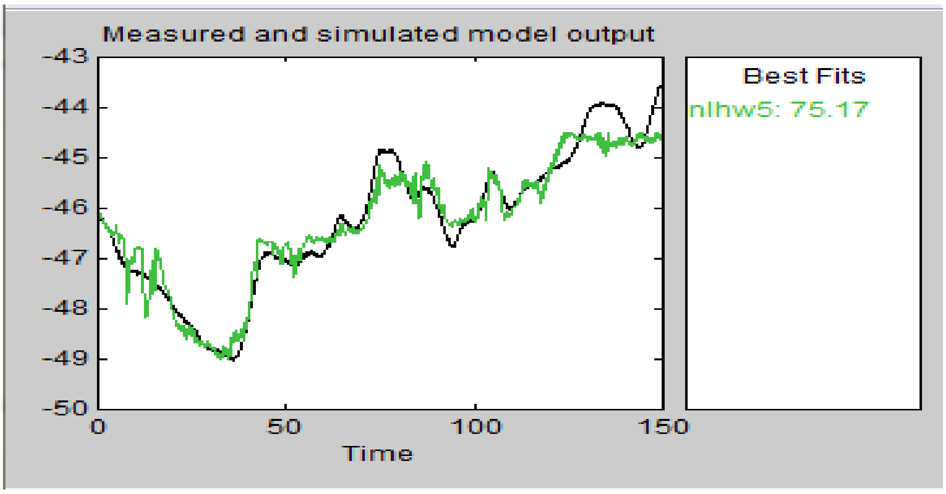
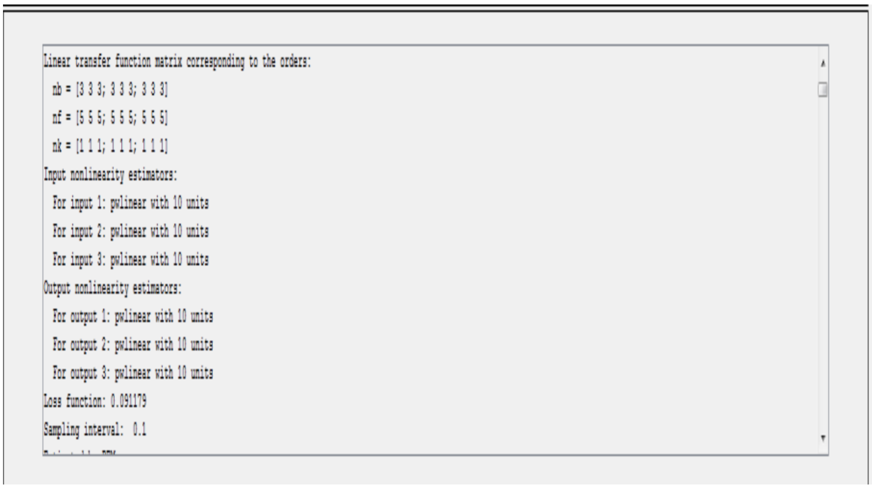


Fig 7 Measured and Model Output

The results of linear transfer function matrix are computed that shows in Fig.8 is for estimating transfer function of lateral and longitudinal dynamics to the fixed wing aircraft as follows in Eq. 2, Eq. 3 and Eq. 4.



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Linear transfer function matrix corresponding to the orders:
  nb = [3 3 3; 3 3 3; 3 3 3]
  nf = [5 5 5; 5 5 5; 5 5 5]
  nk = [1 1 1; 1 1 1; 1 1 1]
Input nonlinearity estimators:
  For input 1: pwlinear with 10 units
  For input 2: pwlinear with 10 units
  For input 3: pwlinear with 10 units
Output nonlinearity estimators:
  For output 1: pwlinear with 10 units
  For output 2: pwlinear with 10 units
  For output 3: pwlinear with 10 units
Loss function: 0.091179
Sampling interval:  0.1
```

Fig 8 Linear Transfer Function Matrix from the Measured Input Output Data's

Longitudinal Dynamics (for pitch input)

$$y_1 = \frac{0.02213z^{-1}+0.005488z^{-2}+0.001692z^{-3}+0.005647z^{-4}-0.03482z^{-5}}{1-0.8222z^{-1}+0.5848z^{-2}-0.7642z^{-3}} \quad (2)$$

Lateral / Directional Dynamics (for roll and yaw input)

$$y_2 = \frac{0.1884z^{-1}-0.3489z^{-2}+0.2819z^{-3}-0.2068z^{-4}+0.08503z^{-5}}{1-0.9022z^{-1}+0.6606z^{-2}-0.7403z^{-3}} \quad (3)$$

$$y_3 = \frac{-0.04709z^{-1}+0.1423z^{-2}-0.1176z^{-3}-0.009642z^{-4}+0.03222z^{-5}}{1-1.578z^{-1}+0.2475z^{-2}+0.3303z^{-3}} \quad (4)$$

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The linear Dynamic invariant system of bode plot and pole zero map were plotted for estimating the relative stability of the aircraft as shows in Fig. 9 by LTI system toolbox.

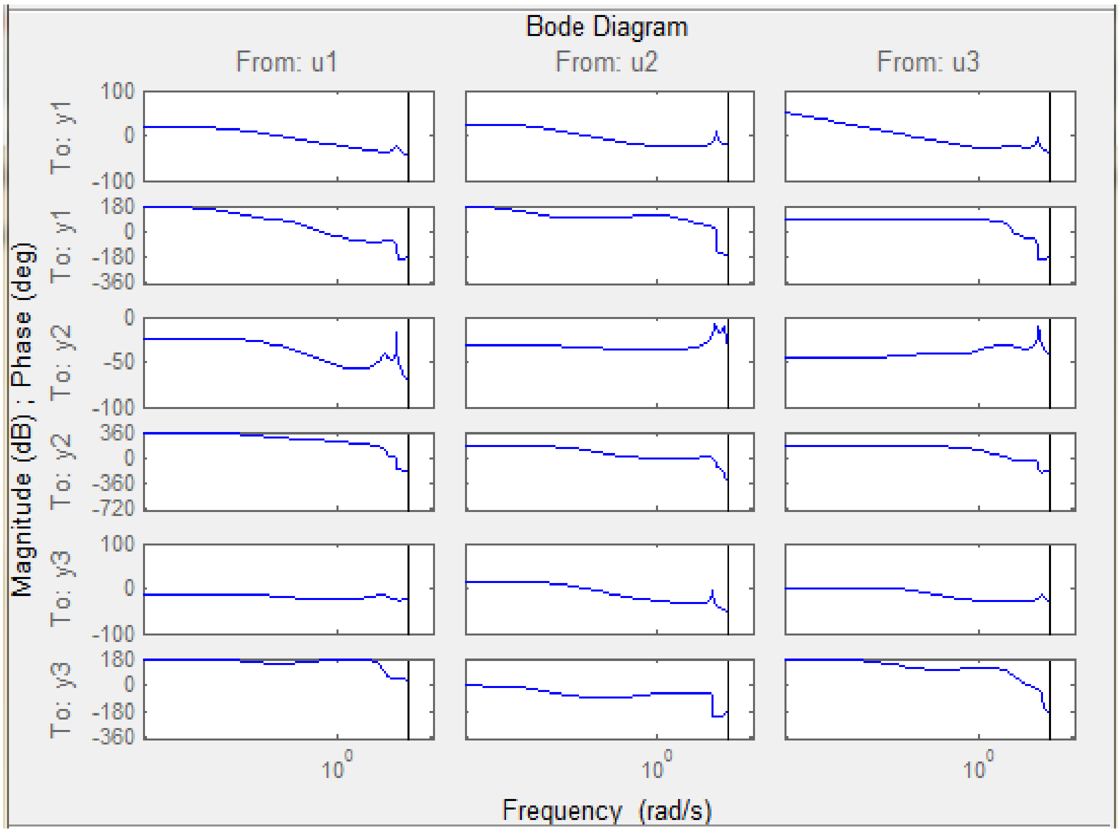

Fig 9 Bode Plot of the Fixed Wing Aircraft Using System Integration Approach

The bode plot have each input and output combination pairs could achieved from that phase margin and gain margin were estimated of the system tabulated in the Table 1.

Table 1. Phase Margin and Gain Margin

		U_1		U_2		U_3	
		PM (deg)	GM (dB)	PM (deg)	GM (dB)	PM (deg)	GM (dB)
Outputs	Y_1	24.60	-119.72	8.44	115.48	17.22	-91.03
	Y_2	9.58	23.50	2.97	Inf	16.64	Inf
	Y_3	0.73	-51.93	2.69	Inf	1.06	Inf

VII. CONCLUSION

In this research paper, the studies of fixed wing aircraft dynamics are discussed by using system identification approach. The data sample has been collected from fixed wing unmanned aerial vehicle along with the help of custom built hardware and software. The generated data's samples are helpful to identify the aircraft transfer function for various flight conditions. It helpful to identify the optimal gain of the fixed wing unmanned aerial vehicle at different flight conditions. It also help to reductions in development time and costs by tracking open and closed loop dynamic response characteristics through its development process.

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