IMPROVING QUADROTOR 3-AXES STABILIZATION RESULTS USING EMPIRICAL RESULTS AND SYSTEM IDENTIFICATION

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***Abstract*— In current literature, Unmanned Aerial Vehicles (UAVs), especially quadrotors, is one of the hot topics of study which has numerous applications. This paper focuses on modeling the quadrotor in order to improve the empirical results. The procedure consists of four stages: 1) Experimental determination of controller coefficients, 2) Data collection, 3) System identification, 4) Controller redesign. After these stages, it is observed that the system is capable of stabilize on the roll, pitch and yaw axes. Coefficient tuning on the identified model noticeably improves the settling time and steady state oscillation amplitude.**

Keywords—linear estimation, aerial vehicles, quadrotor, UAV, four rotor helicopter, vehicle control, Ardupilot.

I. INTRODUCTION

In military and civil applications, the importance of Unmanned Aerial Vehicles (UAVs) is growing. [1-4]. These designs also call for the development of various control methodologies [5-7]. Because of the their maneuverability and small size, quadrotors are very popular. Research efforts on quadrotors include attitude stabilization, estimation and multi-vehicle configurations [8-10].

In this work we attempt to obtain a proper model for quadrotor in order to improve the empirical results. For this purpose we used an ArduPilot board which is a custom design with processor (Atmega168) and arducopter software[12]. In this work instead of designing a brand new system, we attempt to improve the experimental controller on an existing system. After tuning the PID coefficients experimentally, flight data was collected in order to find a proper model using system identification tool of MATLAB. We integrated this model of quadrotor system into simulated controller which exists in arducopter software using Simulink/MATLAB. An important contribution of this paper is to illustrate a simple process to improve empirically determined controllers so as to improve the overall closed-loop response of the system. The rest of the paper will explain the methodology, empirical results and discuss the findings.

II. METHODOLOGY

The basic quadrotor model which is used in this study is shown in Figure 1. F_1, F_2, F_3 and F_4 are the forces applied by the motors. By effects of these forces, pitch angle (θ), roll angle (ϕ) and yaw angle (ψ) are produced.

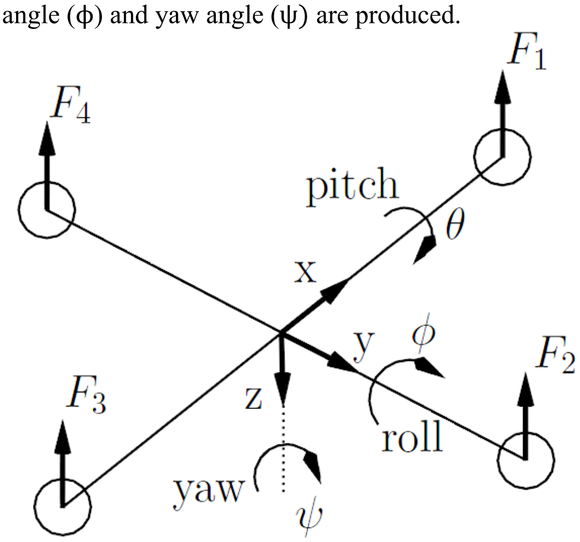

Fig. 1: Simple Quadrotor Model

A. Overview of Ardupilot

The ArduPilot project is low cost solution for autonomous control both Unmanned Aerial Vehicles (UAVs) and Unmanned Ground Vehicles (UGV) which can be seen in Fig.2-1. ArduPilot is an open source autopilot based on the Arduino computing platform which carries ATMega 2560 as processor, MPU-6000 as Inertial Measurement Sensor (IMU), a 5 or 10 Hz GPS module which can be seen in Fig.2-2, a RC module which can be seen in Fig.2-4 and a 915 MHz telemetry which can be seen in Fig.2-3. Since the detailed information about these components is beyond the scope of this work, it is not included. The software named arducopter is written in C++. Due to Ardupilot is an open source project, it is quite appropriate for research projects.

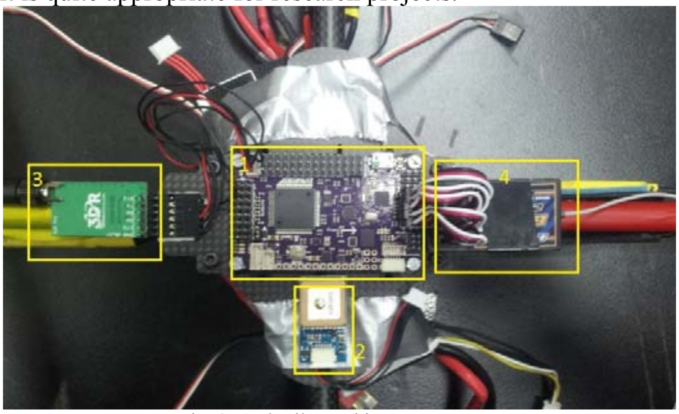

Fig. 2: Ardupilot and its components

B. *Obtaining the Models from System Identification*

Model identification has been made by MATLAB/Simulink. Simulink model has been set up by original code which is written in C and C++. The system can be seen in Fig 3.

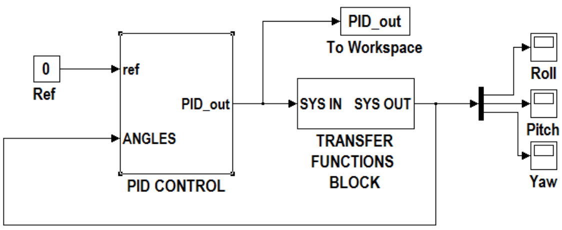

Fig. 3: Simulated roll controller as in arducopter software

System controller out found by simulating flight data. By using these system outputs, we tried to find system transfer function. For this purpose, we used system identification toolbox in Matlab.

Data set measured from experiment has divided in two equal sized data. First divided part has been used for finding transfer function candidates. Second part has used as verification data to find best fitting transfer function according to first data set. Measured and simulated model outputs for all axes are represented in Fig. 4 as accordance with verification data as the part of measured experimental data's second part.

Using results in Fig. 4, we tried to find out systems transfer functions for every axis. These transfer functions are shown in Eq. [1-3]. Eq. 1 is used for roll axes transfer function and Eq 2. is found as pitch axes transfer function. Last of them, Eq 3. is the transfer function result for used in yaw axes.

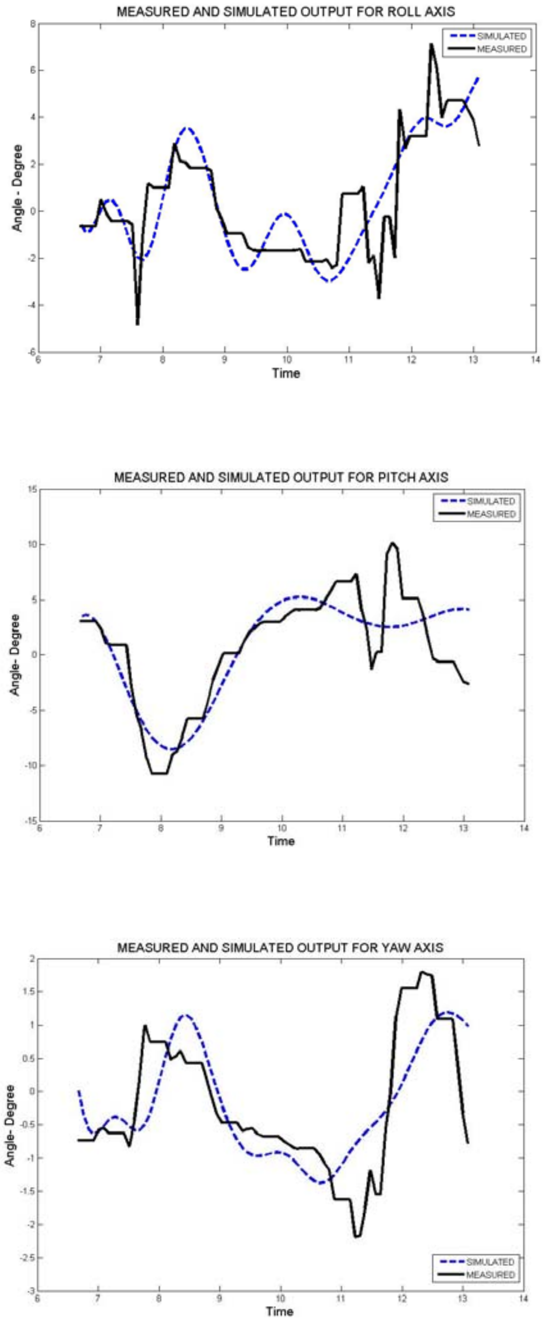

Fig. 4: Measured and Simulated Model Outputs from Simulated System. These model outputs are found for roll(top), pitch(middle) and yaw(bottom) axis. Shown values represents accordance with verification data set.

$$\frac{-953.2\,s^5 + 579.7\,s^4 - 1.04e04\,s^3 - 1951\,s^2 - 409.5\,s + 2024}{s^{10} + 14.78\,s^9 + 121.5\,s^8 + 669.7\,s^7 + 3250\,s^6 + 8328\,s^5 + 2.148e04\,s^4 + 2.614e04\,s^3 + 1.994e04\,s^2 + + 1.08e04\,s + 962.4} \quad (1)$$

$$\frac{1.599\,s^4 - 3.212\,s^3 + 77.97\,s^2 - 17.44\,s + 276.8}{s^8 + 3.79\,s^7 + 67.1\,s^6 + 141.5\,s^5 + 1198\,s^4 + 1018\,s^3 + 3454\,s^2 + 854.3\,s + 469.2} \quad (2)$$

$$\frac{-5.145\,s + 2.629}{s^5 + 3.165\,s^4 + 7.98\,s^3 + 9.194\,s^2 + 7.042\,s + 1.077} \quad (3)$$

C. Controller Simulation in Simulink

Due to improving the empirical results of the overall closed loop controller, we simulated the controller as exists in arducopter software using Simulink/MATLAB.

The main block diagram can be seen in Fig. 3. Transfer function block contains the transfer functions which are obtained from System Identification. PID control block contains three PI controllers for roll, pitch and yaw stabilization.

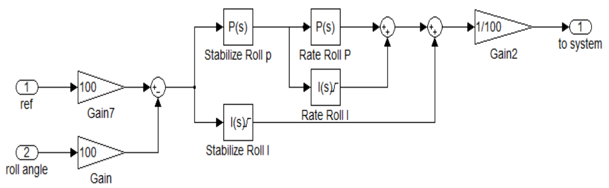

Fig. 5: Simulated roll controller as in arducopter software

The simulated roll controller can be seen in Fig. 5. Since the simulated pitch and yaw controller have the same structure with the roll controller, only the roll control block scheme is shown in the figure.

For stabilization reference, we selected zero (0) degrees for roll and pitch axes, on the other hand, yaw axis used quadrotor's initial yaw angle (in degrees) as the reference of the system.

D. Obtaining Controllers Coefficients

With the model of the system obtained, we now proceed to redesign the controller in order to enhance the performance of the closed loop system, in particular, the time it takes for the system to settle. For this purpose we tuned the P and I blocks in MATLAB's compensator design tool. This process yields the coefficient values $K_p = 4.00$, $K_i = 0.1418$ for roll and pitch stabilization, $K_p = 0.1$, $K_i = 0.0$ for roll and pitch angular rate control, $K_p = 4.50$, $K_i = 0.0$ for yaw stabilization and $K_p = 0.13$, $K_i = 0.015$ for yaw angular rate control.

III. EXPERIMENTAL RESULTS

After changing the controller coefficients another test flight was performed and the flight data was logged (Fig. 7). In Fig. 8, Fig. 9 and Fig. 10 the experimental results with empirical controller coefficients and PID coefficients tuned on the identified model for pitch, roll and yaw angle are shown respectively. Controller stabilization reference is selected as zero (0) degrees for pitch and roll angles and initial yaw angle as for reference for yaw angle. For better understanding, yaw angle degree axis limit ranges are emulated in Fig. 10. It can clearly be seen that the tuned coefficients have improved the closed-loop response significantly; the roll, pitch and yaw angles settle much faster, and the amplitude of the steady state oscillations are lower.

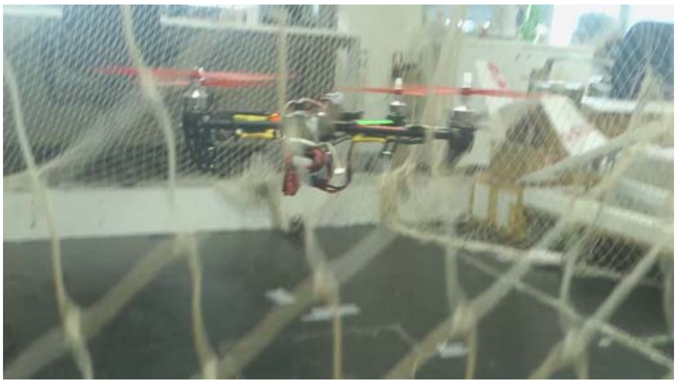

Fig. 7: The quadrotor during flight test with the designed controller

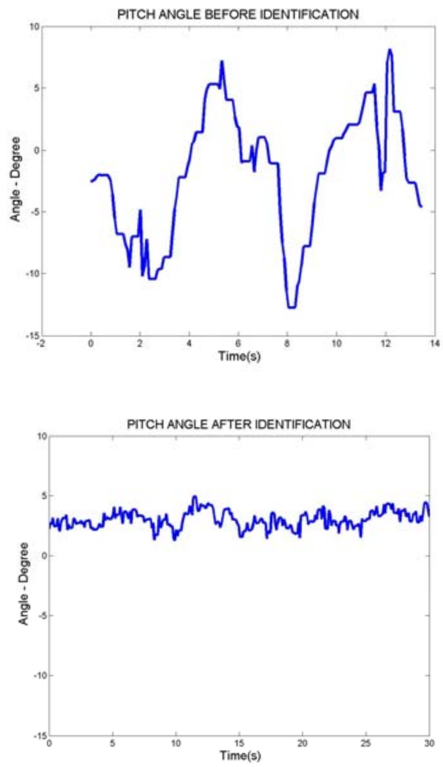

Fig. 8: Experimental results showing the pitch angle (θ) with empirical PID coefficients (top) and PID coefficients tuned on the identified model (bottom)

IV. CONCLUSION

This paper presents a system identification based approach in order to improve the empirically determined controllers so as to improve the overall closed-loop response of the system. First, the controllers coefficients are tuned experimentally due to log the flight data. After the first test flight we obtain three models using MATLAB System identification toolbox, for roll, pitch and yaw respectively. The controller structure in arducopter software is simulated in MATLAB/Simulink. After that the coefficients of the controllers are tuned using the compensator design. The coefficients obtained from this procedure were tested on the experimental setup and it was observed that the settling time as well as the steady state oscillations of the closed-loop system was improved.

Future research directions include redesign the software in order to accomplish other tasks such as aggressive maneuvering and fly capability in bad air conditions.

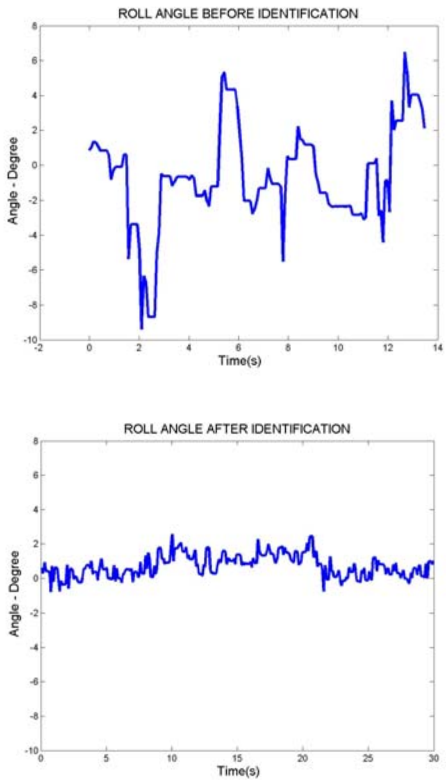

Fig. 9: Experimental results showing the roll angle (ϕ) with empirical PID coefficients (top) and PID coefficients tuned on the identified model (bottom)

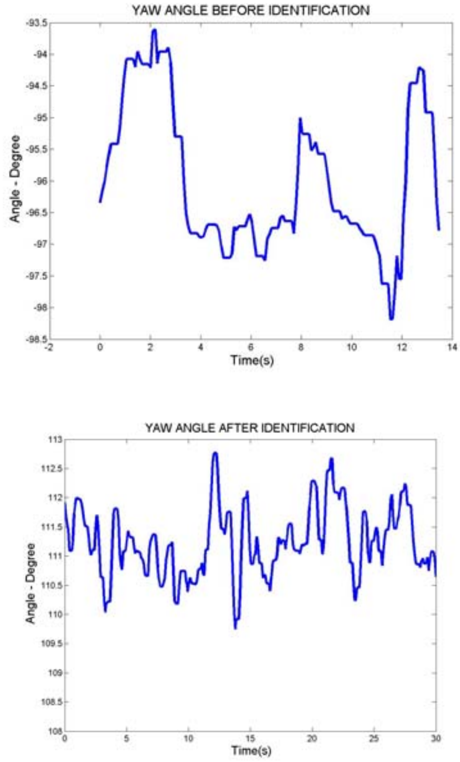

Fig. 10: Experimental results showing the yaw angle (ψ) with empirical PID coefficients (top) and PID coefficients tuned on the identified model (bottom)

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