Quadrotor Control System

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ABSTRACT

In this paper, the quadrotor controller-motor-propeller subsystem and microelectromechanical subsystem (MEMS) are identified and computer model design for the quadrotor control system is developed. Identification stand modifications mentioned in the paper. Control law was based on digital PID controller. The presented solution can be applied in both an indoor and outdoor environment. Computer model angle responses are compared with experimental model responses and analyzed. Furthermore, expected challenges for the future are discussed.

1 INTRODUCTION

Quadrotor is a multirotor unmanned helicopter with a possibility of vertical takeoff and landing. These small autonomous flying systems are highly applicable in many areas of industry and expertise, such as security and safety [1], delivery [2], environmental protection [3], meteorological measurements [4], management of large construction [5]. One of the main technical issue is that a quadrotor is an unstable platform and impossible to fly this unmanned aerial vehicles (UAV) without special control system.

Therefore, in this paper, we consider the problem of stabilization quadcopters for roll and pitch angles. There are different methods for stabilizing these angels varies from most simple PID to difficult as adaptive control. Most common and widely utilized is PID control and its modifications.

For instance, in reference [6] modification of PID controller was investigated. Three structures in respect of the optimal control signal applied to the actuators. Authors examine the different control strategies for the UAV. The cascade PID control system was introduced together with the requirements and appropriate constraints for the system to validate such control algorithm applications in real conditions. In [7], an optimal reconfiguration control scheme is proposed for a quadrotor helicopter with actuator faults via adaptive control and combined multiple models. In [8] authors deal with the modeling, simulation-based controller design and path planning of a quadrotor. A smart self-tuning fuzzy PID controller based on an EKF algorithm is proposed for the attitude and position control of the quadrotor. The PID gains are tuned using a self-tuning fuzzy algorithm.

Therefore, in this paper, the problem of flight stabilization quadcopter for roll and pitch angles resolved based on digital PID controller. The use of this type of control is justified by simplicity and wide coverage. As a control object quadcopter constructed on the basis set DJI ARF 450 KIT is considered.

The mathematical model is introduced in Section 2, while Section 3 presents a identification of subsystems. The control system is described in Section 4, thereafter; Sections 5 contain discussion and concluding remarks.

2 MATHEMATICAL MODEL

Mathematical model of control object is created by simplification of state variables and their derivatives.

Position of UAV in the inertial reference system is defined as $\xi = \begin{bmatrix} x & y & z \end{bmatrix}^T$. The angular position of the object described by the vector $\eta = \begin{bmatrix} \phi & \theta & \psi \end{bmatrix}^T$, where ϕ θ ψ are Euler angles. This way the state vector can be described as $k = \begin{bmatrix} \xi & \eta \end{bmatrix}^T$.

Following simplifications were made: aerodynamic resistance of the object is neglected, object is the symmetrical.

The mathematical model based Newton-Euler equations. In the result, a system of six nonlinear differential equations describing the dynamics of a simplified quadcopters was created:

$$\begin{cases} \ddot{x} = \dfrac{T}{M}(C_\phi S_\theta C_\psi + S_\phi S_\psi) \\[2mm] \ddot{y} = \dfrac{T}{M}(C_\phi S_\theta S_\psi + S_\phi C_\psi) \\[2mm] \ddot{z} = \dfrac{T}{M}C_\phi C_\theta - g \\[2mm] \ddot{\phi} = \dfrac{(J_{yy} - J_{zz})\dot{\theta}\dot{\psi}}{J_{xx}} + \dfrac{\tau_\phi}{J_{xx}} \\[2mm] \ddot{\theta} = \dfrac{(J_{zz} - J_{xx})\dot{\phi}\dot{\psi}}{J_{yy}} + \dfrac{\tau_\theta}{J_{yy}} \\[2mm] \ddot{\psi} = \dfrac{(J_{xx} - J_{yy})\dot{\phi}\dot{\theta}}{J_{zz}} + \dfrac{\tau_\psi}{J_{zz}} \end{cases} \qquad (1)$$

where M- mass of quadrotor; J_{xx}, J_{yy}, J_{zz} - moment of inertia about axis x, y, z, respectively; $C_x = \cos(x), S_x = \sin(x)$.

The mathematical description of the moments and forces are represented in following form:

$$T_Q = \begin{bmatrix} 0 \\ 0 \\ T \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \sum_{i=1}^{4} F_i \end{bmatrix}, \qquad (2)$$

$$\tau_Q = \begin{bmatrix} \tau_\phi \\ \tau_\theta \\ \tau_\psi \end{bmatrix} = \begin{bmatrix} \dfrac{1}{\sqrt{2}}(F_2 + F_3 - F_1 - F_4) \\ \dfrac{1}{\sqrt{2}}(F_2 + F_3 - F_1 - F_4) \\ \tau_2 + \tau_4 - \tau_1 - \tau_3 \end{bmatrix} \quad (3)$$

where F_i - trust force of i-rotor, τ_i - aerodynamic torque of the i- rotor.

3   IDENTIFICATION OF PARAMETERS

In order to control angular position UAV the difference between rotor rotation speed is required. To control the motor speed electronic speed controller (ESC) is used.

For computer model and control system is necessary to know relation between control signal for ESC and trust force produced by motor propeller. Identification subsystem parameters was carried out in two stages using a special stand for measuring trust.

In first stage, the static characteristic of the signal was obtained:

$$F_i(x) = 3.63e - 07x^2 + 0.07688x + 52.16 \quad (4)$$

where x is control signal.

In second stage, identification of subsystem dynamics was carried out. The studies revealed that the subsystem dynamics could be approximately described by a second order aperiodic transfer function. Also studies have shown that subsystem "ESC-motor-propeller" dynamics in acceleration and deceleration modes are significantly different. Therefore, this require separate identification data of the dynamics of different operating modes.

Model takes into account the difference in the dynamics of acceleration (R) and the deceleration (F) modes, the transfer functions of each of the mode represented by the following time constants:

$$\begin{cases} T_{R1} = 0.0551 \text{ s}, T_{R2} = 0.0487 \text{ s} \\ T_{F1} = 0.16 \text{ s}, T_{F2} = 0.025 \text{ s} \end{cases} \quad (5)$$

Figures 1 and 2 are illustrates transient deceleration and acceleration modes at different magnitude of input signal. Highlighted in black graphs is simulation results, measurements are marked in gray.
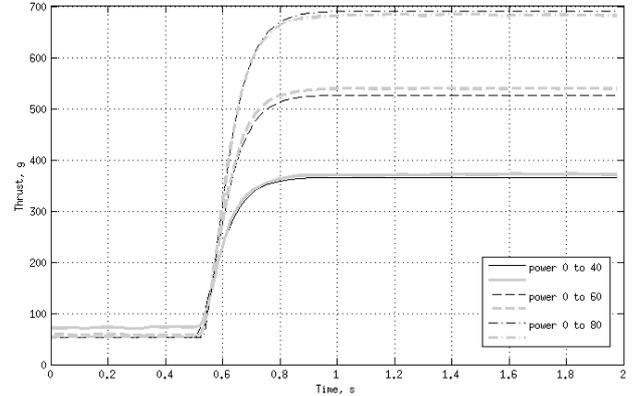

Fig. 1 Dynamic response of subsystem during acceleration Grey: measurements; Black: simulation results
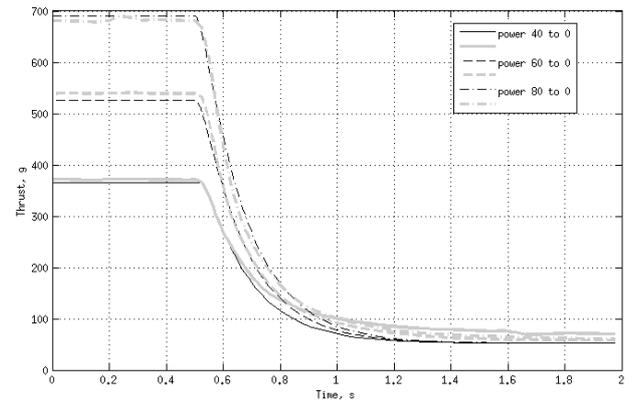

Fig. 2 Dynamic response of subsystem during deceleration .Grey: measurements; Black: simulation results

In this paper, chosen approach to modeling subsystem "ESC-engine-propeller" demonstrated that the maximum error of the simulation results versus measurements was 2.54% of magnitude response signal during acceleration and 5.9% during deceleration.

As a feedback sensors system gyroscope and accelerometer are used. An accelerometer is a sensitive sensor to external disturbances, for example motors vibration. A gyroscope has "zero shift" effect which can affect to control object. As a result complementary filter with low frequency filter are used.

Complementary filter is: r=(1-b)*g+b*a, where r – filtered angle, b – complementary filter ratio, g – integrated gyroscope signal, a – accel-

erometer signal. Usage of filters add some delay to the system. So the value of signals delay should be identified for creation of the quadrotor computer model. Figure 3 is the sensors identification stand. The stand was constructed with usage of accurate potentiometer showing real instant angle position and pitch angle object fixation.

Fig. 3 Sensors identification stand

The sensors identification contributions are 15 milliseconds delay between real angle position and MEMS sensors signals. This result is not proper so future sensors identification is expected.

4   CONTROL SYSTEM

Pitch and roll angles servo systems considered in the survey perform via microcontroller system based on dsPIC33fj256mc710. The mentioned microcontroller has on board motor control generators for motor control via ESC and digital signal processor for mathematical counts acceleration.

The microcontroller system communicates with MEMS sensors subsystem and processes diagnostic information collection on SD-card. Figure 3 is functional diagram of microcontroller system with mentioned serial interfaces.

The experimental quadrotor PID controller rates are tuned via computer model control system PID. The computer model is tuned via Signal Optimisation Package of Simulink. Figure 4 is the computer model of quadrotor with identified subsystems. There are 3 main block in it.
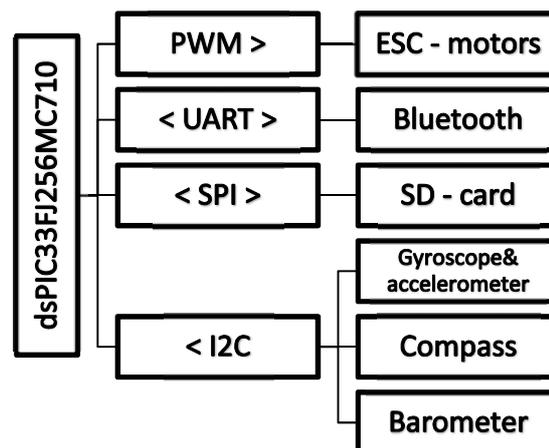

Fig. 3 Functional diagram of quadrotor microcontroller system

The first is the microcontroller, in which take place sampling of signal and control system performance. The second is identified subsystem "controller-engine-propeller", output the thrust in dependence of input PWM signal. In addition, the third is the plant, quadrotor itself, output roll and pitch angles.
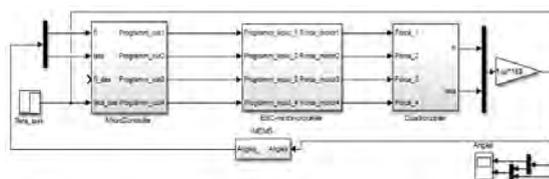

Fig. 4 Quadrotor computer model

The designed computer model and created experimental model allow comparing to models and their transients. Figure 5 is pitch angle transient response of the experimental model with microcontroller system. In comparison, figure 6 is pitch angle transient response of the computer model with identified parameters. Represented figures show similar transients but not identical. Differences between two processes could appear because of incomplete identification of the quadrotor. One and the main parameter of the system is the inertia tenzor that was calculated with the simplified model of quadrotor mass layout.

In this paper PID controller control law was created and represented plots show the oscillating character of stabilization process. This effect is explained via architecture of the control system. Utilizing of another type of control system is expected to improve performance specifications for outdoor usage of the plant with external disturbances.
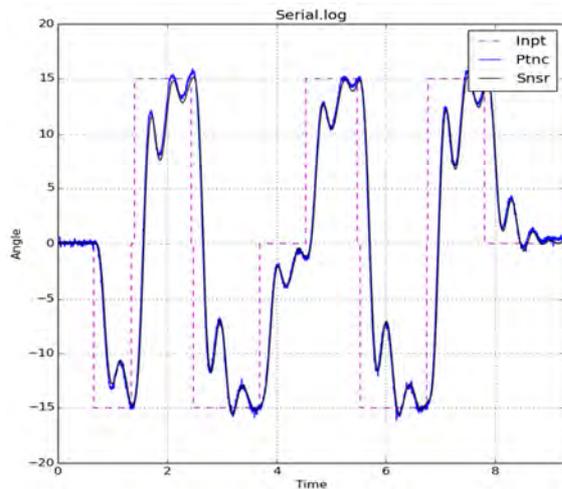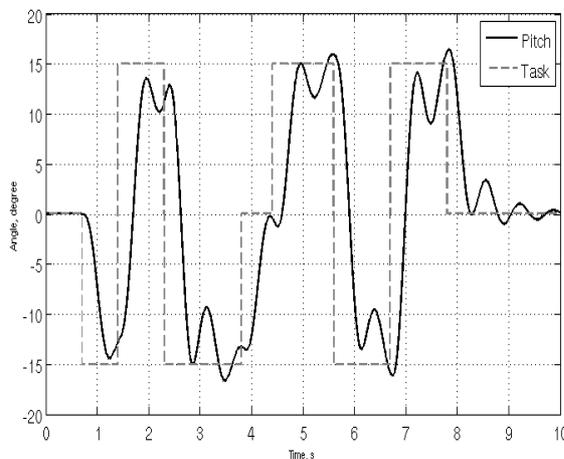
Fig. 5 Pitch angle transient of the real quadrotor

Fig. 6 Pitch angle transient of the computer model

5   CONSLUSION

In this paper research an angular stabilization system for the unmanned platform UAV on example of quadcopter is presented. Computer model of quadcopter was created. Identification of the subsystem "ESC-engine propeller" and sensors subsystem were made and verification of model was performed. The contributions are the base for future studies of the quadrotor.

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