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Designing, Construction and Attitude Identification of a Portable Quadcopter Using Flight Test Data Based on Genetic Algorithm and Artificial Neural Networks

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Abstract

The current research has two main parts, the first part is the process of design, manufacture and selection of quadrotor's elements and the second part is modeling and estimation of model parameters based on flight test data. The main approach of making this drone is to be light and cheap. Also, it is very useful to develop a precise mathematical model for the quadrotor to control the system. Therefore, a system identification method for the quadrotor model based on genetic algorithm and neural network is investigated in the second part. The advantage of system identification based on experimental data is designing a better controller. Autopilot of the quadrotor, control the system to desire attitude by two controller loops by comparing the navigation data with the angle input commands. The existing autopilot has a P outer loop and PID inner loop attitude control, so controllers for the nonlinear model of the system are designed based on this strategy. After designing and implementing the control loops, in order to estimate the parameters of quadrotor, a flight test was performed and the results were stored in autopilot memory. Then using flight test data including angles and rate of them, the identification of the system based on the two methods of genetic algorithm and neural network has been done. For genetic algorithm modeling, a linear second order function is considered for each channel. Meanwhile, it is assumed that the channels are decoupled from each other. The results show that in the roll axis, the results of the identification are the same, in the pitch axis, the accuracy of identification with the second order function and the genetic algorithm method has better results, but in the yaw axis, the accuracy of identification with the neural network is significantly better. In general, the adaptability in all three axes is 81.48% for the genetic algorithm method and 82.62% for the neural network algorithm method.

Keywords: Design and Construction of the Quadrotor; Autopilot; PD Controller; System Identification; Genetic Algorithm; Neural Network.

1. Introduction

Quadcopters are used in urban, intelligence and operational missions, and are very practical due to their availability and high reliability. Since the number of inputs (four inputs) is less than the number of outputs (six outputs) and also because the structure has inherent instability, the quadcopter is an under-actuated system. In other words, the quadcopter is a low-actuator drone that complicates the controller design process.

The exact modeling of the quadcopter's six-degree of freedom (6DOF) has complex nonlinear equations. Therefore, it is very important and necessary to design a controller that can perform properly in all conditions and guarantee the stability of the quadcopter. Meanwhile, the accurate identification of the mathematical model of the system can help to design the appropriate controller. Accurate identification of a quadcopter system is a challenging issue that has been studied in various references.

The identification of a quadcopter system based on genetic algorithm has been done with acceptable accuracy, in reference [1]. In [2], a basic integral method is used to identify the quadcopter system, which is suitable for online identification. The proposed method is compared with traditional methods of system identification and its superiority is shown for step input in the presence of disturbances. In [3], a dynamic model of a quadcopter with internal stabilizer loop is developed by an online identification method in frequency space based on flight data. In this method, first the recurrent discrete Fourier series is expanded for the quadratic transfer function of the channels, then the unknown parameters are computed using the least squares method. Finally, the controller is designed and the flight test results confirm the method.

By studying the literature in the problem of system identification, it is evident that all these methods seek to identify unknown or imprecise parameters, including aerodynamic forces, mass and moments of inertia, and random disturbances. What is very important in identifying the quadcopter model is to create a simple and accurate model at the same time.

The current research has two main parts, the first part is the process of designing, manufacturing and selecting quadcopter elements, and the second part is modeling and estimation of model parameters based on flight test data. For genetic algorithm modeling, a linear second order function is considered for each channel. It is assumed that the channels are decoupled from each other. The second-order decoupling model derived for each attitude state, includes the aerodynamic properties of the UAV without considering the complexities of the six-degree nonlinear models, and to implement the controller, the designer faces a linear second-order model. Validation of the identified model has been done for the quadcopter situation by comparing the results with real flight test data.

2. Methodology

According to the main approach of making this UAV, which is lightness and cheapness, the designed quadcopter has requirements, including:

- Geometric dimensions and mass of sub-systems: the designed structure must have enough space for the arrangement of all sub-systems.
- Propeller diameter: The dimensions of the body should be designed in such a way that the propellers have a safe distance during rotation.
- Double stack PCB: In order to prevent the increase of body dimensions and not to transmit engine vibrations to the navigation sensors, it is recommended to use a double stack PCB.
- Proper field of view for camera.
- Suitable cover so that sensitive electronic parts are protected.

The technical and mass specifications of this autopilot are given in Table 1.

Table 1. Technical characteristics of quadcopter autopilot

Autopilot components	Technical Specifications
Main Processor	STM32F427 Main Processor: Fail-safe Co-Processor: STM32F103
Sensors	Sensors: L3GD20H 16 bit gyroscope LSM303D 14 bit acc / mag MPU 6000 3-axis acc/gyros MEAS MS5611 barometer
Power	Voltage Ratings: Power module output: 4.1~5.5V Max input voltage: 45V (10S LiPo) Max current sensing: 90A USB Power Input: 4.1`5.5V Servo Rail Input: 0~10V
Weight and dimensions of autopilot and GPS/COMPASS module	Dimensions: 38*38*11mm Weight: 13g GPS Module: GNSS receiver: ublox Neo-M8N; compass HMC5983 Weight: 22.4g Dimensions: 37x37x12mm
Input and output ports	Interface: 1x UART Serial Port Spektrum DSM/DSM2/DSM-X® Satellite Compatible Futaba S BUS® Compatible PPM Sum Signal Input I2C CAN ADC Internal Micro USB Port
Usable side sensors	OPTIONAL ACCESSORIES: Digital Airspeed sensor + Pitot tube (MS525DO) Standard Telemetry (433MHz and 915MHz) WiFi Telemetry (2.4GHz WiFi Radio)

This UAV can be seen in Figure 1.

Figure 1. Designed and built UAV

In the flight test, all the navigation information including altitude, longitude and latitude, angular rates, linear speeds, etc. have been collected, with 50 milliseconds sampling time. System identification has been done using genetic algorithm and neural network

3. Discussion and Results

The problem to be solved includes the optimization variables, constraints and the criterion function, which evaluates the criterion function according to a random pattern and calculates the optimal variables while satisfying the constraints. In this UAV, by considering the quadratic model in each attitude channel and having the flight test outputs, the coefficients can be calculated using optimization algorithms so that the difference between output value from the simulation and the actual value are minimized. Therefore, the optimization criterion function is [4,5]:

$$F_{obj} = |y_{actual}(k) - y_{simulation}(k)| \tag{1}$$

The genetic algorithm calculates the values of the coefficients of the transfer functions in each channel with the aim of minimizing this criterion function. Table 2 is the settings considered for the implementation of the genetic algorithm.

Table 2. Genetic algorithm setting parameters

Preferred selection method	Type of genetic makeup	Mutation probability	Generation	Population
Roulette	two points	40%	50	20

The results of modeling and estimation of roll, pitch and yaw angles using genetic algorithm are given in Figures 2 to 4.

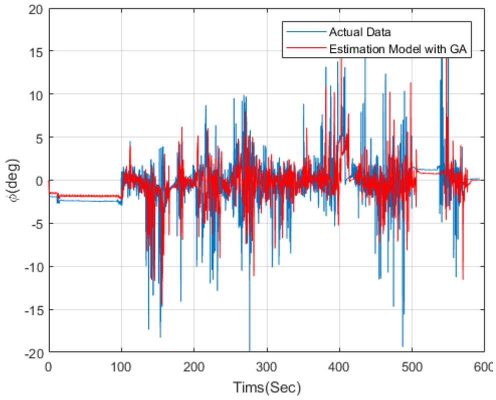

Figure 2. Modeling and estimation of roll angle with GA

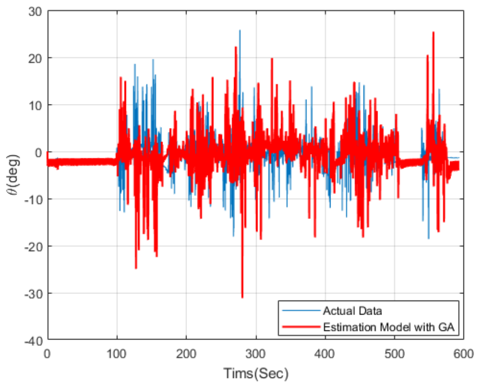

Figure 3. Modeling and estimation of pitch angle with GA

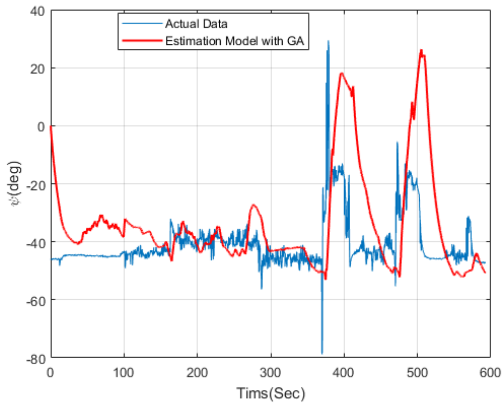

Figure 4. Modeling and estimation of yaw angle with GA

On the other hand, the modeling and estimation results for system angles using neural network can be seen in Figures 5 to 7, respectively.

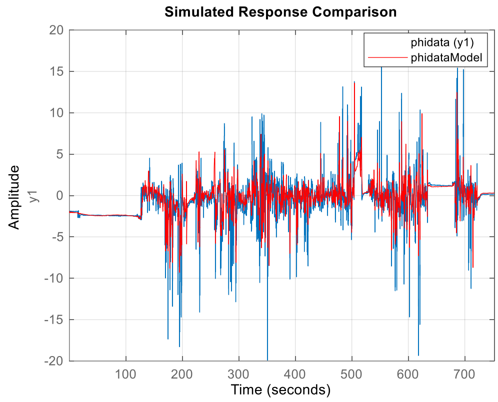

Figure 5. Modeling and estimation of roll angle with neural network

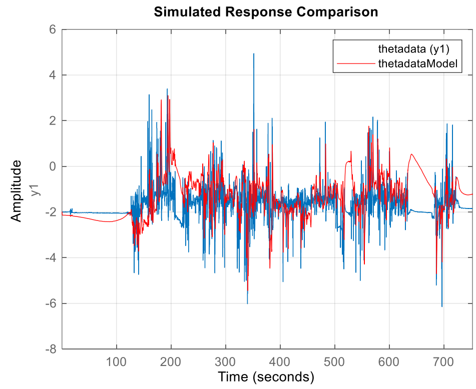

Figure 6. Modeling and estimation of pitch angle with neural network.

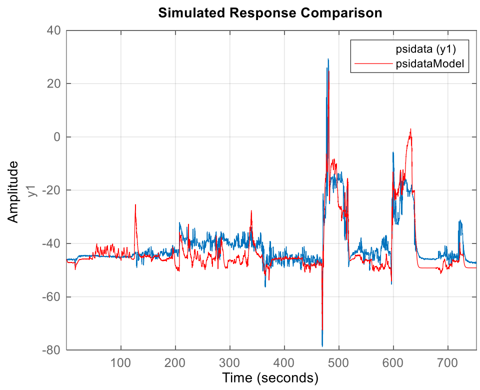

Figure 7. Modeling and estimation of yaw angle with neural network

The comparison between the simulation results based on the identified model and the flight test shows the validity of the identification. One of the methods of comparing two estimates is to measure the matching of the output of the two methods with the actual values. With this relationship, the amount of deviation or adaptation for each angle will be as shown in Table 3. Table 3 shows that with the criterion considered for the error, the extraction of coefficients based on the genetic algorithm in the pitch channel has a better result for identifying the system, and as a result, a more appropriate estimation has been done with the genetic algorithm method. The roll channel identification results are almost the same for both methods, and yaw has much better accuracy in the neural network.

Table 3. Matching percentage criteria for each state channel in genetic algorithm and neural network methods

Method	ϕ	θ	ψ
Matching percentage in genetic algorithm method	72.08	92.17	80.2
Matching percentage in neural network algorithm method	71.14	87.36	89.36

4. Conclusions

In this paper, the design, construction and further identification of attitude channels using flight test data for a quadcopter equipped with an autopilot has been done. Considering that the autopilot used in this article has two control loops, therefore, based on the initial model of the system, the desired controller for the inner and outer loops was designed and then implemented, and after the flight test, the navigation data was extracted. Finally, using flight data, three attitude channels have been identified with two methods of genetic algorithm and neural network. The results show that in the roll channel, the results of the identification are the same, in the pitch channel, the accuracy of identification with the second order function and the genetic algorithm method has better results, but in the yaw channel, the accuracy of identification with the neural network is significantly better. In general, the matching rate in all three channels is 81.48% for the genetic algorithm method and 82.62% for the neural network algorithm method. Therefore, it can be stated that the results of neural network method and genetic algorithm have similar results. According to the extracted models, it is possible to design the desired controller with appropriate precision in the simulators and then implement it in the real system. This article is the first step in the direction of the design of control loops, which can be a great help in the direction of the design of the guidance and control of the position of the UAV, which requires more research work.

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