An Application of 4-Rotor Unmanned Aerial Vehicle: Stabilization Using PID Controller

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Abstract: - This paper has been prepared for designing 4-rotor unmanned aerial vehicle (UAV) and carrying out its control with PID controller. In this context, it divides into four fundamental parts. First part describes what 4-rotor UAV is. Second part is about mathematical model of the 4-rotor UAV. PID controlling and its basic parameters have been analyzed theoretically in the third one. Finally, testing IMU sensors and some controlling applications have been carried out and their outputs have been presented. As a result, the stabilization in desired level has been obtained via designed PID controlling system.

Key-Words: - UAV, PID controller, flight control

1 Introduction

Since eras when people and flying creatures lived together, the act of flying has aroused the curiosity in the human mind. Such being the case, aviation sector becomes one of the fast-growing sectors along with technology. When analyzing the history of aviation, it is seen that air vehicles have ranged from balloon to unmanned aerial vehicles that is, they have varied greatly. This variation led the formation of air power concept which is of greatly importance in terms of defense industry over time. The governments recognize the importance of the air power has considerably invested in this field. Thanks to these investments, many features of the vehicle such as technical parameter, control algorithm, and maneuverability etc. have developed and increased. Accompany these, when the literature is analyzed, it is seen that the studies on this field have increased. For theoretical models of quadrotor aerodynamics to be analyzed by using helicopter momentum and blade element theory [1], for an unknown parameter belongs to quadrotor to be identified with the help of Unscented Kalman Filter [2], for adaptation to unknown payloads and robustness to disturbances to be achieved [3], for the method aiming at solved problems resulted from dynamic characteristics of a quadrotor to be proposed [4], the design of nonlinear modeling of quadrotor and obtaining its mathematical model [5], quadrotor performance and design of a PID controller for stabilization of the dominant decoupled pitch and roll models [6], for quadrotor propellers to allow to tilt [7], for coaxial quadrotor to be designed [8], for aerodynamic and mechanical model of

UAV constructed from carbon composite material to be designed [9], for the nonlinear dynamic model of a quadrotor and its controlling to be examined [10], developing a cascade control method for superheated processes [11], for the architecture of a quadrotor and analyzes the dynamic model of it to be described [12], an implementation of computer vision to hold a quadrotor via a low-cost, consumer-grade, video system [13], using sliding mode disturbance observer (SMC-SMDO) approach for designing a robust flight controller [14], designing a controller making use of the block control technique for trajectory tracking of a quadrotor [15], presentation nonlinear robust control method for solving the problems on path following [16], proposing attitude control strategy based on variable structure control theory [17], capable of attitude estimation and stabilization of unmanned aerial vehicle [18], analyzing the attitude control of a rigid body [19], quadrotor flight in terms of vision-based obstacle avoidance [20] can be given as examples of the studies in point. When comparing the above mentioned studies, this paper focuses the subjects such as construction and balance stability of quadrotor and obtaining some control parameters of the rotors.

2 Quadrotor

The point on air vehicles reached in recent times is design of unmanned air vehicle (UAV). UAV have lots of important advantages. First of all, errors arise from human factor are minimized. This is of great significance in terms of reducing crashes. And also, it enables the possibility to saving space so they can be produce smaller sizes. Small sizes contribute high performance maneuverability, wide range of use, ease of control and command. Because unmanned vehicles have such features, they become one of the most engaging areas.

UAV divide into some categories and have many different types. One of them is multi-copters. They can be termed as tricopter, quadrocopter, hexacopter, octocopter according to their rotor's number.

In this paper quadrotor which has four rotors, capable of vertical take-off and landing and the type of rotary wing aircraft has been dealt with in some several ways. Its principle of flying is similar to helicopter. There is a significance difference between them. Whereas the swivel action is blocked via tail rotor in helicopter, it is blocked for pairs of rotors to be controlled in the opposite direction.

3 Mathematical Model and PID Control

Mathematical model is the first step for the designing a quadrotor. It includes aerodynamic and mathematical equations and the equations at issue are described according to the axes. The axes are shown in Fig. 1.

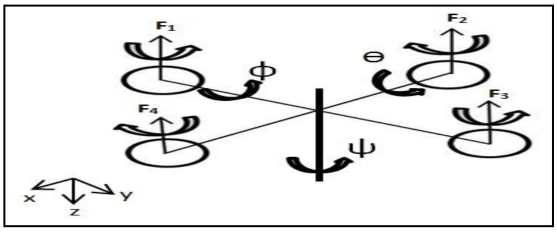

Fig.1 The axes used for modelling a quadrotor

Control of quadrotor is carried out replacing the propeller turns using the axes and the parameters shown in Fig. 1. The parameters are from F1 to F4 represent forces of thrust and ψ, Θ, and ϕ represent angles of roll, pitch, and yaw. These turns generate forces of momentum and torque for maneuverability. Additionally, many controlling method are used for stability of the quadrotor. One of them is PID controller which describes the functions applied the error of the system. It names derive from the first letter of the words proportional, integral, and derivative. All functions affect different factor belongs to the whole system. Proportional controller symbolized with coefficient of Kp improves the accuracy of the static and dynamic response of the system. Integrator controller symbolized with coefficient of Ki increases the amount of static accuracy dynamic response by waiving. Derivative controller symbolized with coefficient of Kd is increases or improves the dynamic response. The important point is for the appropriate parameters to be calculated and all parameters are in relation each other shown in (1) and (2).

$$Ki = Kp / Ti \quad (1)$$

$$Kd = Kp * Td \quad (2)$$

Ti parameter shown in Eq. 1 refers to reset time and Td parameter shown in (2) refers to how many times Kp multiplied in the minutes that is response speed of the system. In this sense, mathematical definition of the PID controller is given as follows:

$$PID = Kp + Ki / s + Kd * s \quad (3)$$

$$PID = Kp + \frac{Kp}{Ti * s} + Kp * Td * s \quad (4)$$

In Fig. 2, it is shown that application of PID controller covers the parameters in point to a system.

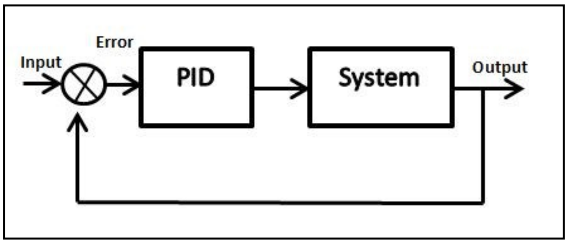

Fig.2 Applying the PID controller to the system

The PID controller is a combination of PD and PI controllers. It can be used to improve the steady state error and the system transient response. It is popular for industrial application. In this study, PID controller will be used. The parameters of PID controller are found by trial and error.

4 Testing IMU Sensors and Control of Stabilization

This part of the paper includes some IMU sensor testing and controlling stabilization with PID controller. The testing divides into two categories as on ground and in flight mode. Aims of the testings to determine the operate performance of the sensors and obtained effectivly operated controller. If they are not provided, the quadrotor can not be used and carried out special tasks.

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First of all, initial values and the problems in this situation are of great importance. In this sense, the initial values of the quadrotor have shown in Fig. 3.

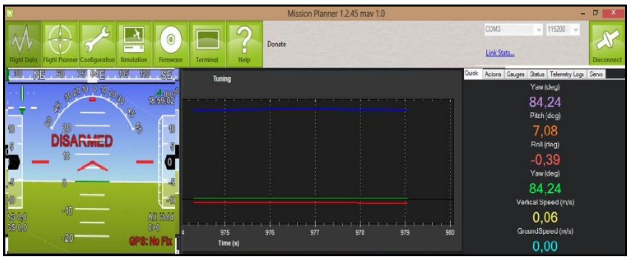

Fig.3 Initial values of the quadrocopter

There is important point on angle of pitch. Because we are not in sea level, its value is 7.080 on artificial horizon indicator. Also it is seen that initial value of yaw angle is 84.240 and roll angle is -0.390. Additionall signal of "+" refers to right or up, signal of "-" refers to left or down in figures.

4.1 On Ground Testing

Aim of this testing part is comparing with desired level and response of sensors during the quadrotor is on ground mode. And desired values have applied to the system via remote control device.

In first testing, it is desired that angle of roll is increased 5.10 positive directions and this command has applied to the system. The result of this command is shown in Fig. 4.

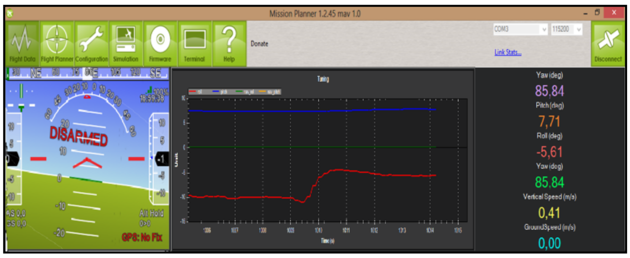

Fig.4 Results of the roll angle alteration

It is demonstrated that the angle has reduced from -0.390 to -5.610 so it is increased 5.220. It means steady state error is 2.35 %.

In second testing, it is desired that angle of roll is reduced 90 in negative direction and this command has applied to the system. The result of this command is shown in Fig. 5.

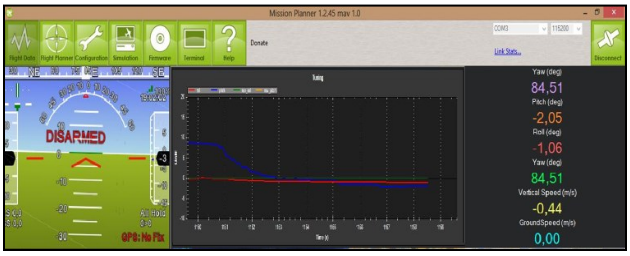

Fig.5 Results of the roll angle alteration in negative direction

It is demonstrated that the angle has reduced from 7.080 to -2.050 so it is increased 9.130. It means steady state error is 1.44 %.

In third testing, it is desired that angle of pitch is increased 7.60 and this command has applied to the system. The result of this command is shown in Fig. 6.

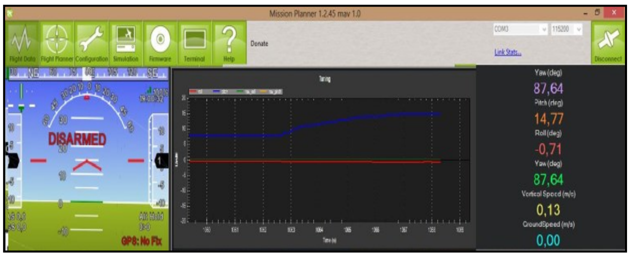

Fig.6 Results of the pitch angle alteration

It is demonstrated that the angle has increased from 7.080 to 14.770 so it is increased 7.690. It means that steady state error is 1.18 %.

The fourth testing is different from the abovementioned ones in terms of types of sensor used. The data of this measurement have obtained with barometrical pressure sensor which integrated to IMU. The command has been applied to system is increasing angle of pitch 20.10 negative direction. And the result of this command is shown in Fig. 7.

Fig.7 Results of the pitch angle alteration in negative direction

It is demonstrated that the angle has reduced from 7.080 to – 13.260 so it is increased 20.340. It means steady state error is 1.19 %.

4.2 In Flight Performance

Aim of this testing part is comparing with desired level and response of sensors during the quadrotor is in flight mode. And desired values have applied to the system via remote control device.

The testing has been carried out is about GPS. For this testing, approximately 3 m altitude has been gained to the quadrotor. This can be seen in the Fig. 8 as the value of "alt" parameter.

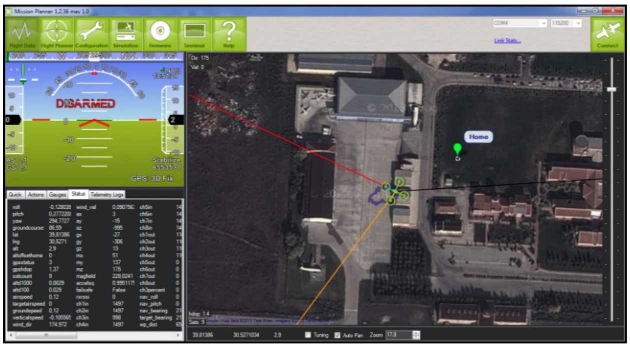

Fig.8 Result of GPS testing

The data obtained in this situation has been compared with the original data. As a result of this comparing, it follows that the data obtained are true.

4.3 Control of Stabilization

In this part of the paper includes some PID control applications and these applications have been carried out to remove or minimizing some undesired situations.

The initial values of the PID parameters have been demonstrated in Fig. 9.

Fig.9 Initial values of the PID parameters

In the situation with initial values, it is seen that the system has slow vibration speed, short response time and big movements in roll axes. For solving these problem, value of Kp parameter within stabilize roll has been reduced as considering effects of it to the system (Fig. 10).

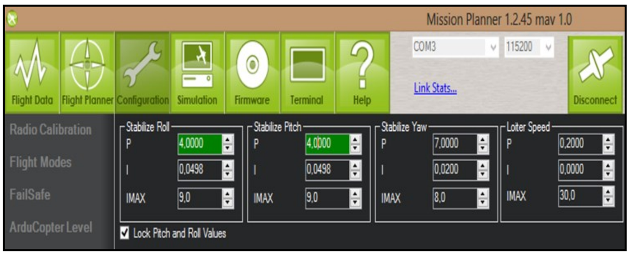

Fig.10 Setting of Kp parameter in stabilize roll

The setting has removed the big movement in roll axes and reduced the vibration, but disturbed the stabilization of take off and landing performance. For solving this problem, value of Kp parameter within rate roll has been increased as considering effects of it to the system (Fig. 11).

Fig.11 Setting of Kp parameter in rate roll

The setting shown in Fig. 11 has provided stabilization and minimizing the vibration. Also response to disturbance effects has been eliminated.

5 Results

When building a quadrotor, working of sensor and control system are of great importance for operating performance of it so this paper has been dealt with in this context.

The testing cariied out are about the sensors integrated in IMU. From these sensors the data relative to angle of pithc and roll has only been tested. The testings about angle of roll shown in Fig. 4 and Fig. 5 has set forth that the steady state error changes between 1.440 % and 2.350 %. These value are in accepptable limits, so it can be said that the sensors operate accurately and sensitively. The testings about angle of pitch shown in Fig. 6 and Fig. 7 has set forth that the steady state error

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changes between 1.180 % and 1.190 %. These value are in acceptable limits and they can be dismiss according to its field of use, so it can be said that the sensors operate accurately and extremely precise. Other application is validating GPS data. For these validation, the altitude has been gain to the quadrotor and desired data has been obtained as shown in Fig. 8. After that, the data has been compared with original values. From this comparing, it follows that GPS data can be obtained correctly.

The last applications are about setting the parameters of PID controller. For this aim, first of all initial values and the problems in this situation has been defined as shown in Fig. 9. After that, for solving these problem, the values of the parameters has been set as shown in Fig. 10 and Fig. 11. Finally the settings to be provided desired situation has been achieved.

The achievements sets forth that the quadrotor operate effectively and can be used in variable tasks.

6 Conclusion

The developments and especially nano-technology have provided opportunities for dimensions and components of the vehicles to be produced much smaller sizes. And also, vehicles can be produced faster and higher processing capacity when comparing with those of the past. Quadrotor is one of the such vehicles and analyzed in this paper in terms of working operate and controling.

When considering the paper as a whole, it follows that the quadrotor has been built successfully. Also result section sets forth that undesired situations has been removed and minimized with PID controller by setting its parameters. These settings are indicator that effects of a controller designed successfully provide the system with many advantages. More over, this paper is the first study to be carried out in Anadolu University in this field. In this sense, it becomes an example for succeeding studies to be fulfilled in both the university and others.

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