



Quadcopter Stability Increased by PID Adaptive Tuning

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Today's World is getting more efficient in mail deliveries or other applications using autonomous vehicles as drones because of their improved performances. The quadcopter appertains to the drone family having the advantage of flying stability light weight and accurate maneuverability. This paper describes the design and the adaptive tuning for dynamic control of a quadcopter using PID control technique. The experimental tests show improved response related to the previous results under the same input conditions.

Keywords: *adaptive tuning, dynamic control, flying stability, PID algorithm, quadcopter*

1. Introduction.

The quadcopter or quadrotor, Unmanned Aerial Vehicle (UAV), is a kind of helicopter having a four rotors type-design for two pairs of opposite rotors, rotating clockwise and counter-clockwise to balance the torque. The roll, pitch, yaw and others are controlled by changing the rotor rotation, using Pulse Width Modulation (PWM) to accomplish the desired action.

These aerial vehicles, UAVs or MAVs, are used for mail deliveries, aerial photography, mapping, inspection of power lines, atmospheric analysis, traffic monitoring, border patrol, fire detection and natural disasters.

Quadcopter have not complex mechanical control, because of the fixed pitch rotors, and it uses the variation of motor speed for vehicle control [1]. This simplified structure become a disadvantage, since controlling a quadcopter is not easy due to the coupled dynamics and the fix design configuration [2]. Also, the dynamics of the quadcopter is not so linear and several uncertainties can be encountered during the mission [3]. Thus, making its flying mode more stabilized becomes challenging in any case. In the literature, several control algorithms and tuning methods were identified. In this paper, a three-step tuning of PID specific gain values is

proposed, in order to improve the dynamic stability, and for this aim a simple but effective test stand was designed.

2. Analysis background.

In flight mode, the quadcopter generates the lift forces by controlling the fixed pitch angle rotor speeds. If the center of mass is considered in the origin O of a 3D coordinate system and the forward direction is arbitrarily assumed along x-axis, to lift off from ground (along z-axis), all four rotors are rotated at the same speed in the sense. A total thrust equal to the weight of the system stabilizes the system in space. To roll about the x-axis, differential thrust of rotors on the y-axis should be applied. To pitch about the y-axis, differential thrust of rotors on the x-axis should be considered. The yaw motion is achieved by the differential thrusts of the opposite rotors, while also adjusting the constant thrusts of the remaining opposite pairs to maintain altitude [5].

The dynamic behavior of the quadcopter requires high control and each control algorithm scheme has its own advantage and disadvantage. Generally, the control schemes used could be categorized as linear or non-linear [4].

PID controller has been implemented in a wide range of control applications, being recognized as the most applied controller in industry [6]. The classical PID is a linear controller and it has the advantage of easy to adjust the parameter gains, simple design and good robustness.

The major challenge in regard of the quadcopter is the non-linearity associated with the mathematical model and the imprecise nature of the model due to unmodeled or inaccurate mathematical modeling of some of the dynamics. Therefore, performing classic PID control limits the performance of the quadcopter.

Let's exemplify some cases. The PID control has been implied in the attitude control of a quadcopter [7], and by applying Lyapunov stability criteria all signals of the quadcopter were uniformly ultimately bounded. This meant that the quadcopter was stable for hovering conditions. The simulation and the experimental plots reveal that the PID control performed better in the pitch angle tracking, whereas large steady state errors could be observed in the roll angle tracking.

Another example is in [8], where a PID controller has been implemented to adjust the position and the orientation of a quadcopter. Here, the PID parameter gain values were chosen intuitively and the performance of the PID controller shown a quite good stability, the response time was good with almost zero steady state error and a slight overshoot.

Among these researches we propose a three-step adaptive structure (3-SAS) based on PID control algorithm. This 3-SAS was introduced in a quite common PID control architecture [9].

3-SAS supposes a logic structure modification in the source code of the numerical PID controller. Thus, instead of one initial set of values for the PID gain control (K_p - proportional, K_i - integral and K_d - derivative), three sets were pro-

vided in a sequential structure that manages the movement stabilization in relation to the values acquired from the gyroscopic sensor. The range of values given by the gyroscopic sensor is split in three sub-ranges: 0 - 30 %, 30 - 60 % and 60 - 100 %. To each range, one set values of PID gains have been assumed. When the measured gyroscopic value changes the range, automatically PID gains assume the corresponding set of values. In this way, PID becomes adaptive and its performances are increasing.

To better define the area of this research, we have to mention some aspects from the beginning:

- simulation model was simplified to the measurement / transient data, the weight setpoint variation from the control interface was ignored, giving a fix value;
- only a triaxial gyroscopic sensor for rotation was implied, the displacements along axes were ignored;
- roll, pitch and yaw movements were tested and tuned up one at the time;
- the flight was dynamically simulated by using a stand that offers the possibility to take the quadcopter in a limited area;
- due to the limited area, a serial wired connection is possible and data from the gyroscopic sensor and the output for PWM motor control have been acquired for comparison.

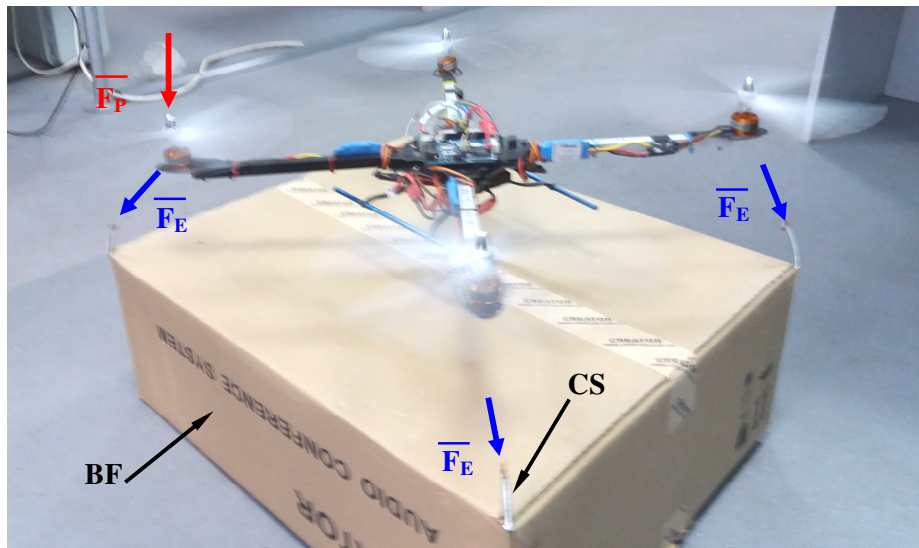


Figure 1. Image of the dynamical simulation of quadcopter in flight mode

In figure 1 the image of a dynamical simulation of the quadcopter is given. The simulation scenario is completely defined by the following:

- the possible action point of perturbation force (F_p);

- the direction, sense and place of elastic force (F_E), which maintain the quadcopter near the fixed base frame (BF) with the help of the four coil springs (CS).

3. Tests and results

Tests were performed on roll movements and they show interesting reactions of quadcopter. It sharply actuated the horizontal equilibrium position even for high variation of displacement or to very dense and big impulsive perturbation.

Table 1. The input ranges and the PID gain sets

Range [%]	Movement	Proportional	Integral	Derivative
0 - 30	Roll	1.0	0.34	0.3
30 - 60		1.5	0.7	0.6
60 - 100		2	1	0.8
0 - 30	Pitch	1	0.5	0.2
30 - 60		1.2	0.7	0.4
60 - 100		1.5	1	0.7
0 - 30	Yaw	0.6	0.2	0.1
30 - 60		0.8	0.4	0.3
60 - 100		1	0.7	0.5

After performing many tests and repetitive tuning adjustments the more proper PID gain sets for the measured input gyroscopic values acquired in various scenarios have been summarized in table 1.

The tuning strategy is described in several materials [10], the major part of them is posted on internet and they can be easily accessed. It should be mentioned that not only the PID set values and tuning strategy are important, but also

the choice of propellers, motors, frame support structure and weight are often very determinative.

In the case of the roll movement, the values of output have been normalized to the input and graphically represented in figure 2, for some considered important situations.

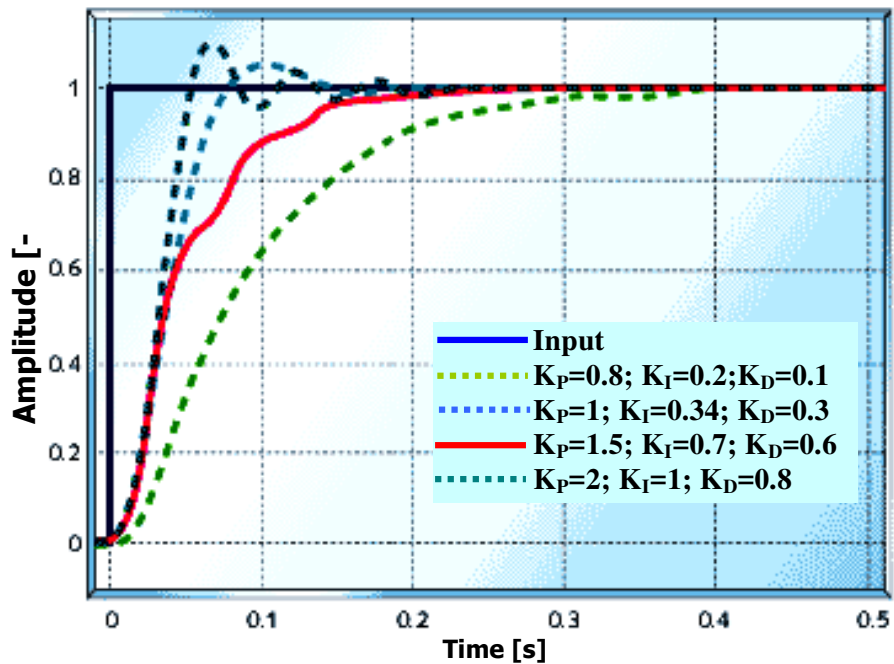


Figure 2. PID controller tuning progress

In figure 2, it is enough visible the time improvement and the best output accomplishment in dark-green.

4. Conclusion.

In the paper a new way of PID numerical implementation is described and afterwards tested and finally proved as effective. The new implementation is actually an adaptive algorithmic structure based on PID control strategy.

This new approach of PID implementation shows more adaptive behavior, and by the three sets of PID gain values speeds up the reaching of steady state level to almost three time faster than usual 0.3 seconds.

References

- [1] Huo X., Huo M., Karimi H.R., *Attitude Stabilization Control of a Quadrotor UAV by Using Backstepping Approach*, Mathematical Problems in Engineering, 2014, 1-9.
- [2] Mahony R., Kumar V., Corke, P., *Multirotor Aerial Vehicles: Modeling, Estimation, and Control of Quadrotor*, Robotics Automation Magazine, 19, 2012, 20-32.
- [3] Lee B.-Y., Lee H.-I., Tahk M.-J., *Analysis of Adaptive Control Using On-Line Neural Networks for a Quadrotor UAV*, 13th International Conference on Control, Automation and Systems (ICCAS), 20-23 October 2013, 1840-1844.
- [4] Astrom K.J., Murray R.M., *Feedback Systems-Second Edition*, Princeton University Press, Princeton and Oxford, 2018.
<http://www.cds.caltech.edu/~murray/FBS>
- [5] Zulu A., John S., *A Review of Control Algorithms for Autonomous Quadrotors*. Open Journal of Applied Sciences, 4, 2014, 547-556.
- [6] John S., *Artificial Intelligent-Based Feedforward Optimized PID Wheel Slip Controller*, AFRICON, 12 September 2013, 1-6.
- [7] Lee K.U., Kim H.S., Park J.-B., Choi Y.-H., *Hovering Control of a Quadrotor*, 12th International Conference on Control, Automation and Systems (ICCAS), 17-21 October 2012, 162-167.
- [8] Li J., Li Y., *Dynamic Analysis and PID Control for a Quadrotor*, International Conference on Mechatronics and Automation (ICMA), 7-10 August 2011, 573-578.
- [9] ***** <https://oscarliang.com/quadcopter-pid-explained-tuning>.
- [10] ***** <https://fpvfrenzy.com/pid-tuning-resources>

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