Wind-Adaptive Self-Balanced Control for Quad-Copter Using Embedded Method

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Introduction:

Quad-copter, also known as quad-rotor, is hot among researchers all over the world because of its stability and VTOL (Vertical Take-Off & Landing) feature, simplicity in flying mechanism [1] and small size. Lots of applications like surveillance, reconnaissance, rescue missions and aerial imagery [2] are achieved using the quad-copter UAV (unmanned aerial vehicle) platform. However, miniature quad-copter in flight is influenced badly by sudden airflow, which will cause serious fluctuation, leading to deviation to the original course or even plane-crash. To make a better chance for a quad-copter to survive in sudden airflow, we come up with an idea: build a module that gives adaptability to the quad-copter, so that it can change control system parameters to increase the stability in windy condition while keeping good performance in normal condition (indoor, or outdoor with mild wind).

Methodology:

Control System of quad-copter:

PID (proportional-integral-derivative) controller is widely used since it doesn't require knowledge to the physical model of a quad-copter.

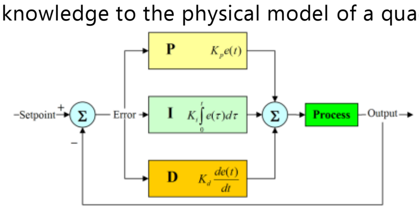

Fig1: Typical PID control system [3]

Assumption/Definition/Remark:

After some research, we make the following definition and assumption:

DefinitionⅠ: The stability is achieved if the deviation angle of roll (φ), pitch (θ) and yaw (ψ) to their set-point is bounded in ±2°. [5][6]

DefinitionⅡ: PID_o/PID_w is the PID parameters in normal/windy condition.

AssumptionⅠ: The quad-copter is a symmetrical rigid body. [7]

AssumptionⅡ: PID_o is the optimal PID parameters in normal condition.

RemarkⅠ: The deviation of yaw angle (ψ) is not taken into consideration.

With AssumptionⅠand RemarkⅠwe determine that *the stability of the quad-copter about x-axis is the same as the stability about the y-axis*. Also after simulating and analyzing the PID controller output using Matlab, one conclusion is made: *It is not possible to have one set of 'all-mighty' PID values that works perfectly in both situations ('normal' and 'windy').*

Wind-simulation methods:

Method 1: Simulate the sudden change of deviation by changing the set-point of roll/pitch angle.

Method 2: Generate wind using a commodity fan.

Steps: (Quad-copter is fastened on a platform that only allow it to roll/pitch)

Part 1: Using wind-simulation method 1

1) Use method 1 to find a set of PID values (PID_w) that provides short transient time.
2) Analyze the behavior of transient time when changing the P and I value.
3) Analyze the performances of the roll/pitch angle with updated PID values in both normal and windy condition.

Part 2: Using wind-simulation method 2

1) Analyze the deviation of roll angle in normal condition with PID_o.
2) Analyze the deviation of roll angle in windy condition with PID_o.
3) Analyze the deviation of roll angle in windy condition with PID_w.
4) Compare the result from step 2 and step 3, to see whether the performance in windy condition is improved.
5) Test PID_w in normal condition, to see whether it performs worse than PID_o.
6) Repeat step 1 – 5 for pitch angle.
7) Analyze the data log in step 1 and step 2 to see how to characterize 'windy' condition for the quad-copter.
8) Design a autonomous PID parameters changing system for the quad-copter.

Result:

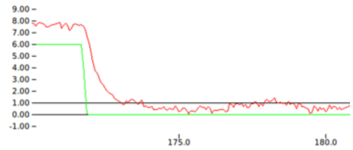

Fig2: Roll angle with smaller PI values

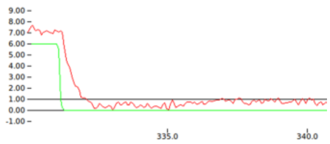

Fig3: Roll angle with larger PI values

Green curve is the set-point value; red curve is the roll angle estimation value. Increase the P and I values do shorten the transient time of the roll angle after a sudden change of set point. However, when keep increasing the P and I values, a much shorter transient time can be achieved but oscillation will occurs.(See Fig2 and Fig3)

Fig4: Roll angle in normal condition with PID_o

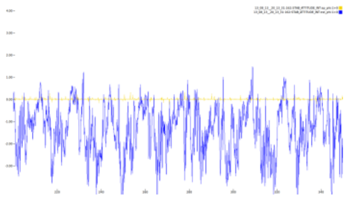

Fig5: Roll angle in windy condition with PID_o

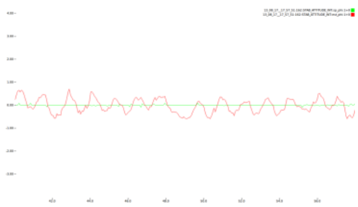

Fig6: Roll angle in normal condition with PID_w

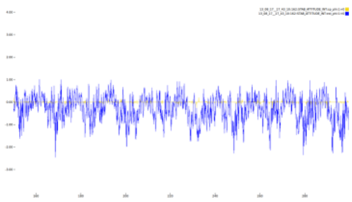

Fig7: Roll angle in windy condition with PID_w

Conclusion:

Through the experiment, we try 3 different PID_w (PID_w1, PID_w2, PID_w3) with increasing PI values. However, we get a unexpected outcome: the PID_w1 performs better than PID_o in both condition (normal/windy); and PID_w (PID_w1, PID_w2, PID_w3) have almost the same performance in windy condition with Method 2 while PID_w1 having the best performance in normal condition, although PID_w2 and PID_w3 have shorter transient time than PID_w1 in Method 1.

We analyze the outcome make some conclusion:

1) It's hard to find the 'optimal' PID values; This experiment is based on the Assumption Ⅱ which may not be guaranteed.
2) Wind is too variable; PID values with good performance in Method 1 don't ensure good performance in Method 2.

At last, we propose a possible solution in the final report.

Reference:

[1] Hoffman, G.; Huang, H., Waslander, S.L., Tomlin, C.J. (20–23 August 2007). "Quadrotor Helicopter Flight Dynamics and Control: Theory and Experiment". *In the Conference of the American Institute of Aeronautics and Astronautics.* Hilton Head, South Carolina.

[2] http://en.wikipedia.org/wiki/Quadcopter

[3] http://radhesh.wordpress.com/2008/05/11/pid-controller-simplified

[5] John S.Denker, "Coordinate Systems, Basis Sets, Reference Frames, Axes, etc.", available: http://www.av8n.com/physics/coords.htm#main-ned

[6] S. Bouabdallah, R. Siegwart, "Design and Control of a Miniature Quadrotor", in *Advances in Unmanned Aerial Vehicle, 2007* Springer, Printed in Netherlands, chapter6, pp171 - 210

[7] Jun Li, Yuntang Li, "Dynamic Analysis and PID Control for a Quadrotor", Proceedings of the 2011 IEEE