CALIFORNIA STATE SCIENCE FAIR
2016 PROJECT SUMMARY

Name(s)

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Project Number

S0313

Project Title

Stabilizing a High-Power Quadcopter

Abstract

Objectives/Goals

I was a member of a Stanford UAV club project that built an ultra-high-powered quadcopter with a thrust-to-weight ratio of 8:1 (0 to 60 mph in 0.34 seconds). We hoped to break a world record for fastest quadcopter. Because the quad was constructed from off-the-shelf parts that were known to work well, we expected it to just fly. But instead it just crashed immediately.

I was responsible for getting the quad to fly. I had to modify the stock firmware of the flight controller and the electronic speed controls (ESCs) in order to stabilize such a high-powered quadcopter.

Methods/Materials

I came up with the following procedure for determining and fixing the cause of the crashes. First, I lowered the power of the quad (by modifying the ESC firmware) until the quad flew stably. Then, in successive flights, I gradually increased the power until I observed a problem with the quad's flight behavior. Once I identified a problem, I modified the flight controller firmware to eliminate it. Then I continued to increase the power so I could observe any more problems.

Results

I identified and repaired the following problems with the flight controller's firmware. First, I had to fix a bug that caused an uncontrollable throttle increase during a hover. Second, I had change the firmware to allow PID constants less than 0.001.

The third problem required a particularly involved solution. The flight control firmware used a single set of PID gains for the entire throttle range. Unfortunately, my flight testing showed that a single set was insufficient for a high-power quadcopter. So I modified the firmware to implement a 10-segment piecewise-linear gain curve. I devised a novel procedure for determining the required gains at 10 points in the throttle range.

Conclusions/Discussion

I concluded that conventional flight control software can't be used to fly a high-power quad stably, without modifications. The methodology I devised: starting with conventional power levels and gradually increasing the power, allowed me to identify and fix problems in the flight control firmware. I showed that PID gains need to vary with the throttle, and a piecewise-linear curve can implement this variation. My experiments for determining the shape of this curve yielded a surprising result: the piecewise-linear curve is U-shaped rather than monotonically decreasing as is widely believed.

Summary Statement

I stabilized an ultra-high-power quadcopter through firmware modifications.

Help Received

Dmitry Turbiner, Eli Wu, Gordon Sun, and Russell Kao collaborated with me on the design and construction of the quadcopter. Eli recommended using BLHeli flight controller. Dmitry suggested scaling PID gains based on throttle.