Analog Electronics Final Project Report

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Overview

The goal of this project is to create an analog circuit that can process the output of an accelerometer, interpret the orientation, and based on set values produce the required output to drive four motors on a quadcopter to balance the system.

Control Circuit

For this project we chose an accelerometer from Freescale Semi (FXLN8361QR1) which operated between 1.7 V and 3.6 V. The device can also toggle between a low sensitivity mode ($\pm 8g$) and a high sensitivity mode ($\pm 2g$). When the power is supplied and mode set, the accelerometer outputs three voltages proportional to the acceleration in X, Y, and Z.
Thus on level ground at rest, the accelerometer should measure a net acceleration of $[0, 0, -g]$. However, at zero acceleration, the device outputs an offset voltage of 0.75 V, thus the equilibrium position in terms of voltage will be $[0.75\,V, 0.75\,V, 0.979\,V]$.
To determine this equilibrium, we need to integrate the Z signal twice to determine the net displacement, and select for the height we wish to hover at with a comparator. Then to balance, we also integrate both X and Y signals once to select for zero velocity. Since the comparator will output a rail voltage based on the net difference between measured value and set point, it must be scaled to appropriately control the motors to restore balance.

Motor Control

To control the motors, it is first important to understand the motors themselves. Quadcopters no longer use simple DC motors to control their speed, since they are not precise enough. Instead, they use what is known as three-phase AC signals. Each AC signal is 120 deg out of phase with each other, to trigger one of three electromagnet in the motor.
The frequency determines the rpm, which is precisely controlled by an electronic speed controller (ESC). This ESC measures the back emf of the first two poles to determine the phase shift of the third pulse.

The ESC in turn is controlled by a pulse width modulated (PWM) square wave from a central control system, such as a micro-controller or an analog circuit. The throttle it applies to the motors is controlled by the duty cycle of the wave, which can be simply generated by using a triangle wave and a comparator.
By comparing the output of the triangle wave to a set voltage, the resultant signal will either go to zero or the upper rail, with the width of the pulse equaling the width of the triangle wave that is above the set voltage. This the duty cycle of the square wave can be controlled simply by adjusting the set voltage of the comparator.
Figure 1 shows the required circuit to accurately create the PWM signal. Testing this circuit revealed that a set voltage range 2 and 4V results in a duty cycle between 25% to 65%. The triangle wave itself needs to range from 0 to 5V to register properly.

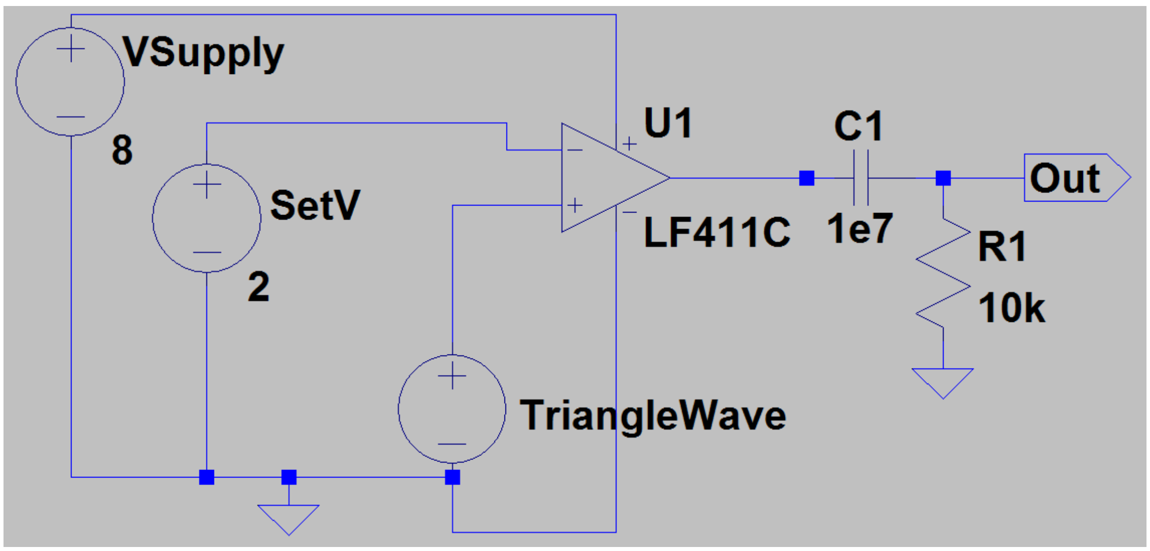


Figure 1: Schematic of PWM Circuit, consisting of a triangle wave, a set voltage, an opamp acting as a comparator, and a low pass filter.

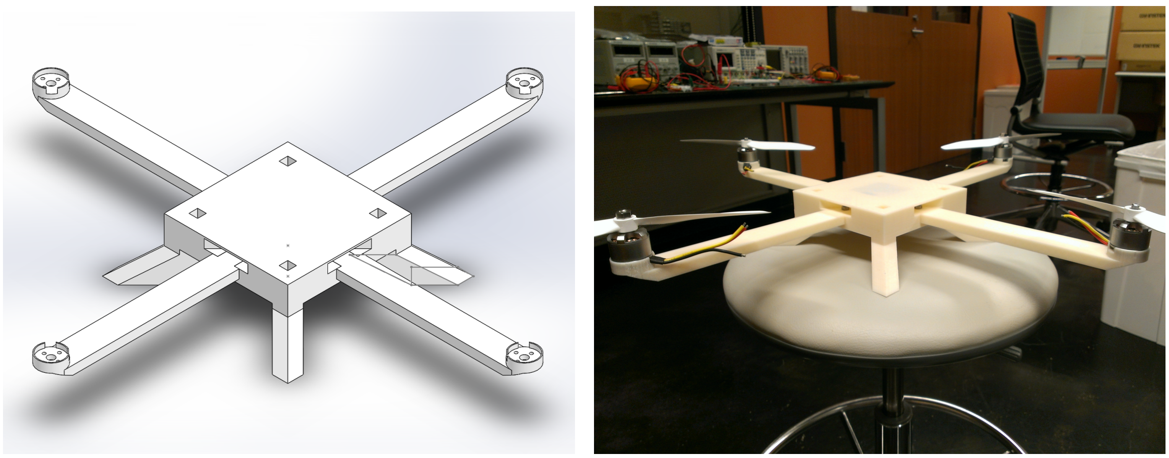
Mechanical Design

The quadcopter itself had very few mechanical constraints, however the chassis did need to accommodate the following parts at minimum:

- Motors (x4)
- ESC (x4)
- Battery

- Central control board
- TTL board (x4)

The only parts that have an exact mechanical requirement are the motors, which have threaded holes for M3 bolts at the bottom to panel mounting. Thus it was decided to utilize the 3D printer at OIST to produce a custom designed chassis for the quadcopter, as shown in Figure 2. Each arm has room for the motor to be mounted, along with space for



(a) 3D Render in Solidworks

(b) 3D Printed Chassis with motors attached.

Figure 2: 3D render of quadcopter chassis, with room for motors, battery, and requisite electronics.

the corresponding ESC to be mounted underneath with zip ties. Each arm locks into the central body, and is secured using an M5 bolt. The top section has holes to allow zip ties to wrap around the inner section to hold down the central electronics. Finally the bottom of the central piece has an additional hollowed section to more zip ties to hold the battery underneath, keeping the center of gravity low.

Feedback

The feedback mechanism in this system is not strictly electrical, but related through the orientation of the copter. The motors represent the final output stage of the control circuit, which will affect the orientation of the quadcopter. This in turn affects the output voltages of the accelerometer, which represent the inputs of the control circuit.
Thus to properly describe the feedback of this circuit, it is important to understand how much thrust the motors supply, and how that force twists the orientation of the quadcopter.

In order to do this, the thrust must be characterized as a function of voltage, which is described in the appendix of this report.

Problems and Issues

This project ran into a lot of setbacks, mostly logistical but also due to poor planning. The initial concept of this project assumed that the quadcopter motors we would buy were simply DC motors, as opposed to three-phase AC motors. DC motors would have required a much simpler design, and proven more feasible for a project of this scope. Instead we were forced to redo our entire design to account for our quadcopter motors.

After some experimentation in building a three-phase AC circuit and consultation with online forums, we realized not only would this not be enough, but that we could not power the motors without a minimum of 8 A, well beyond the capabilities of the power supplies provided. This required us to put in a second order for an appropriate battery and set of motor controllers.

Although we were able to finally obtain a functional accelerometer board to test, without the motors running there would be no need for a quadcopter. Thus while this report covers the entire scope of the intended project, the actual work achieved is limited to the control circuit and mechanical design.

Conclusion

In conclusion...

Figure 3: Diagram of the experimental setup for characterizing the motors.

Appendix A: Characterizing Motors

Given a fixed motor and propeller combination, the only variable that can be adjusted in the RPM, which in turn determines the upward force each motor can generate. Although it would be possible to calculate this force numerically with the specific shape of the propeller, it is far more efficient to simply characterize the force as a function of voltage directly.

To accomplish this, the setup shown in Figure 3 will be used: a series of weights will balance the motor and propeller on either side of a pulley system. The motor will be connected to the ESC and PWM circuit, so it can be directly controlled by adjusting the set voltage on the comparator. As the voltage is increased (thereby speeding up the motor), additional weight will be added until the system comes to equilibrium again. This additional weight directly represents the force applied by the motor, and will allow us to construct a rudimentary characterization curve for our calibrations.