Autonomous Quadcopter
FINAL REPORT
Group 5
5/4/10

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"I pledge my honor that I have abided by the Stevens Honor System"

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I: Abstract

The United States border patrol effort is a multibillion dollar a year organization which uses an arsenal of land, sea and air vehicles, along with foot soldiers to patrol the U.S. border in various locations. Border patrol operation consists of over 19,000 employees trained to seek and defend against drug smuggling, illegal immigration, and terrorist activities at the border. The operation consists of these hired soldiers and civilians who patrol the U.S. border using an assortment of land, air, and sea vehicles.

The purpose of our senior design project is to create an aerial Quadcopter to autonomously patrol the border and wirelessly report suspicious findings by using an array of onboard sensors. Our vision is that with several hundreds of our robots autonomously monitoring and surveying the border, the man power and government resources needed to run such an operation would drastically decrease, along with drastically reducing the potential for human endangerment while protecting the border. We also intend to design the autonomous robot with a universal payload bay to increase the diversity of applications our robot can adhere to. Depending on the robots intended function and the topographical location in which it is being deployed, the user will be able to select from a range of peripherals applicable to any given situation.

I-1. Acknowledgement

This project would not have been completed without Professor Yi Guo who was not only our advisor but encouraged and guided us throughout the semester. The group would like to extend our thanks to our senior design advisor Prof McNair and Mary Schurgo. We would also like to thank Kyle Barr, graduation class of '10 for his extensive help in the making of our SolidWorks model.

II: Project Progress

II-1: Introduction

The design approach the team is implementing in the prototype is very similar to the original design as described in our previous reports. The prototype is an autonomous aerial vehicle (AEV) with the ability to fly independently of an operator all while relaying real-time information to a base station and simultaneously receiving instructions directing our robot to its next task. The robot is designed to be self-sufficient, allowing it to communicate to a base station with little intervention by the users of the system, which in turn allows for a wide range of users and implementation scenarios.

The prototype consists of a light weight carbon fiber frame attached to which are four motors that receive power from electronic motor controllers that allow communicate with the microprocessor, which will in turn control the speed of each individual motor. This design, while simple in theory, gives us a very robust and flexible platform when implementing various design elements. Using a four brushless motor Quadcopter design we are able to change directions, elevation, and tilt rapidly by simply manipulating how much voltage goes into the motors while the AEV is in the air. We have implemented a multiple-axis accelerometer and gyroscope to allow for multiple degrees of freedom when reading information regarding the status of the Quadcopter. The use of these sensors allows us to maintain stability in constantly changing atmospheric conditions. The system itself is powered by a high capacity lithium polymer battery capable of a high discharge rate, allowing for sustained flights and adequate power supplied to the system at all times. This system, with all of its parts working in harmony, creates a stable and flexible platform on which can be built a system to meet the needs of a variety of users.

II-2: Prototype Specification

Design Goal

Our design goal for a prototype UAV was to build a platform capable of providing stable flight in order to survey the UAV's surroundings. We chose a quad-rotor system that uses an accelerometer and gyroscope to provide stability while in flight. The Quadcopter would also have the ability to carry an extensive payload including IR sensors, night vision camera, or even food and medical supplies.

Quadcopter Theory

Our Quadcopter uses four propellers, each controlled by its own motor and electronic speed controller. Using accelerometers we are able to measure the angle of the Quadcopter in terms of X, Y, and Z and accordingly adjust the RPM of each motor in order to self stabilize its self. The Quadcopter platform provides stability as a result of the counter rotating motors which result in a net moment of zero at the center of the Quadcopter.

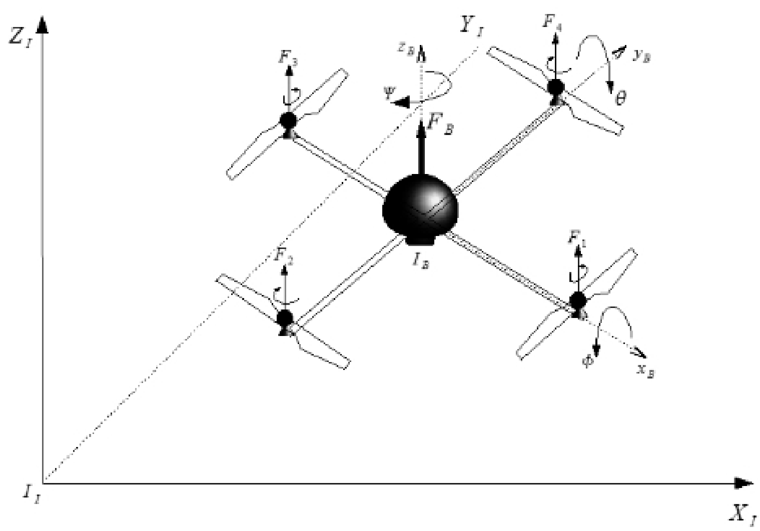


Figure shows net moment at F3 = 0

Using this principle we are able to adjust the speed (RPM as a function of the voltage provided to the motor) of each individual motor in order to correctly manipulate Quadcopter's yaw, tilt, and roll. Tilt and roll can be controlled by changing the speed of the appropriate motors, while yaw control involves delicate balancing of all four motor functions in order to change the moment force applied to the quad.

Our Design

Our Quadcopter frame is made out of light weight carbon fiber square tubes attached in a cross configuration (Appendix B). Our Quadcopter uses the Arduino ATmega168 microcontroller to process to interpret accelerometer data and adjust the voltages of each motor. The microcontroller operates at 16 MHz and has 14 digital I/O pins along with 6 analog input pins. The Arduino schematic is in Appendix C. We have also included the transmitter and receiver to control all the functions (throttle, tilt, and roll) of the Quadcopter in order to make the initial testing phase easier and safer.

Our Quadcopter runs on 11.1v lithium-ion polymer 3 cell batteries which carry a charge of 4000 mAh and a max current load of 60 Amps. Our motors operate between 9-12 volts and have the ability to produce 1000 RPM per volt provided. The battery also provides power to all individual circuits providing a stable 5 volts to the Arduino board. The wiring diagram for the complete system is provided in Appendix C.

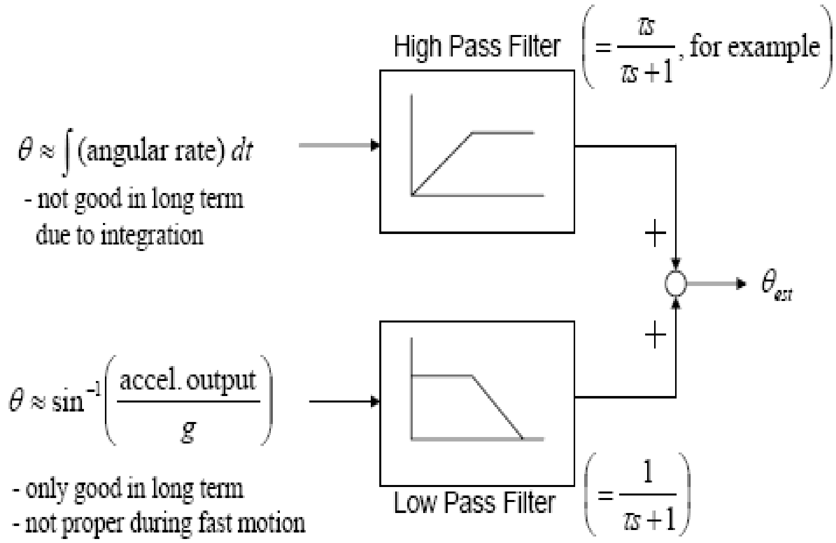
Our Inertia Measurement Unit consists of a dual-axis gyroscope and a triple axis accelerometer in a tight footprint. The IMU has 5DOF and allows for sensing of Roll, Pitch, X, Y, and Z. The IMU reports data to the microcontroller 500 times a second, and uses an ultra low operating voltage of 3V. A schematic of the IMU is provided in Appendix C.

Figure shows our 5DOF IMU

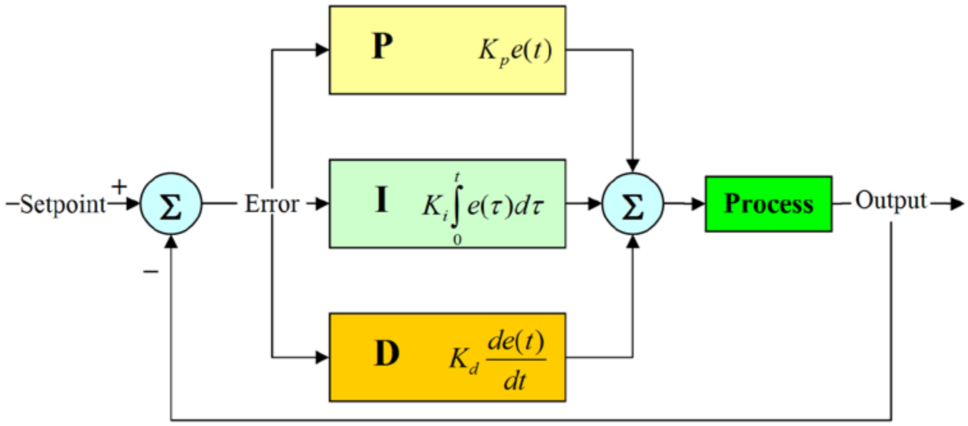
Software implementation

We chose to program our project in objective C since all the group members were familiar with the language. From the beginning, the emphasis on software was based on speed. The quicker we can read in the accelerometer data, process the information, the quicker we can figure out how much more or less each individual motor needs to work, and relay that change to the motor controller. The quicker this process happens, the more stable the Quadcopter will have. Both software flow and architecture diagram is available in Appendix C.

Our software uses complementary filtering to choose the best source of angular measurement. The accelerometer provides accurate short term measurements, where as the gyroscope is better in reading the angle over a longer period of time. We sample both the accelerometer and the gyroscope and scale the outputs depending on the speed and the movement of the quad copter. We chose complementary filtering instead of the commonly used Karman filtering since the latter was harder to implement in the software and was a resource consuming sub routine.



The software also uses a PID controller to reject errors from the IMU to make the inputs into the microcontroller more accurate. In conjunction with the complementary filter, the PID controller is able to vary the responsiveness of the motors of the Quadcopter. For example we can tune the PID control loop such that the quad copter motors will react quicker when it detects a change in angle. Tuning the PID parameters had been a big hassle, and has resulted in many crashes. We had to find the perfect PID balance in order to make our Quadcopter hover successfully. Initially we thought of setting the PID loop for maximum responsiveness, meaning the quickest possible response from the motors once the angle is measured. Upon testing however, we saw that these PID values resulted in an oscillation of the quad while it was flying, eventually this built up to the point where the Quadcopter completely flipped over. The PID loops was too quick, and before the Quadcopter was returning to a level hover, the PID loops caused it to oscillate back and forth violently. Thus we came to the conclusion that we had to lessen the effect of the PID loop so the quad would have time to return to a level position and then continue balancing itself. During test flights we saw a dramatic improvement with the stability.



II-3: Prototype Performance and Evaluation

Smooth filter test

A smooth filter is a low pass filter that can help us filter the random disturbance from the outside world. The smooth factor, which is an abstraction of RC value in a low pass filter, ranges from 0 to 1. To decide the value of the smooth factor, we did some tests to see how the data is filtered with varying smooth factor values.

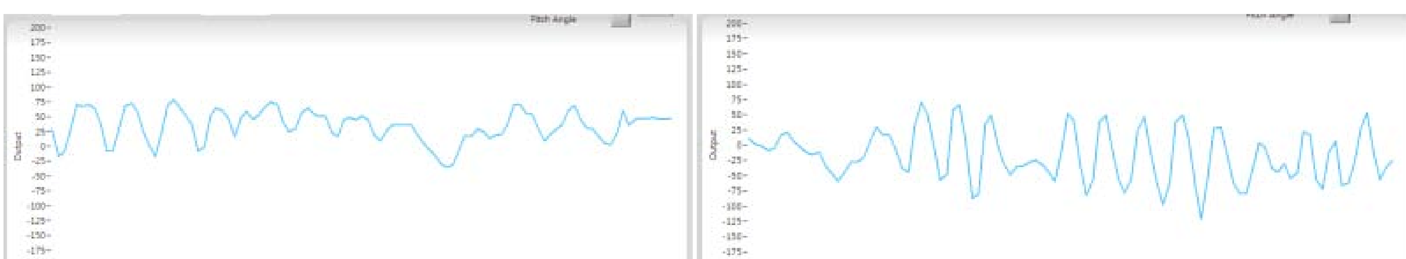
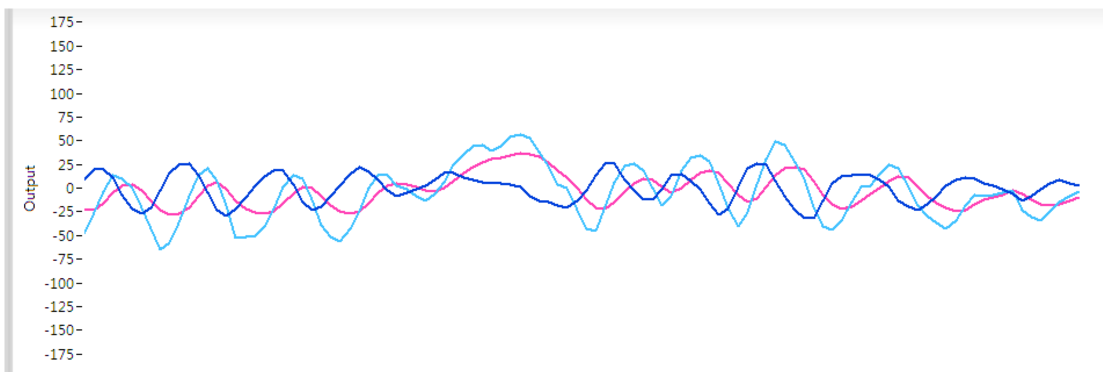


Figure shows fluctuations according to different smooth factor values.

We read in the x-axis accelerometer data and output the filtered data. We generated two plots when the smooth factors are 0.1 and 0.5 separately. From the plots we did not get any significant difference in terms of the smoothness of the curve so we decided to use 0.5 as the smooth factor

Complementary filter test

A complementary filter is used in our design because the angle data obtained from the gyroscope is accurate in high frequencies and the angle data obtained from the accelerometer is accurate in low frequencies. Therefore we used the complementary filter to combine the high frequency region from the gyroscope and the low frequency region from the accelerometer data together to get the real angle. The implementation results are as follows:



The dark blue line represents the angle of y-axis got from the gyroscope, and the light blue line represents the angle of y-axis got from the accelerometer. The filtered angle is showed in purple.

PID parameters adjustment

PID controller is a widely used control loop feedback mechanism. The PID loop uses the P or proportional value to determine the reaction to the current error. The I or integral value determines the reaction based on the sum of total errors, and the D or derivative value determines the reaction based on the rate at which the error has been changing. The PID parameters are usually determined through experimentation and our current PID values are P = 5.2, I = 0.1 and D = -10.0.

To determine the P value, we set I and D as zero, and then we tilt the Quadcopter to one side slowly. During the process we should feel a force that tries to stop the tilting of the Quadcopter. If the force is too strong, we decrease the P value, if it is too weak, we increase it.

To determine the I value, we set P and D as zero, and then we tilt the Quadcopter to one side slowly. The ideal value would be able to stop the Quadcopter from tilting more than 20 – 30 degrees.

II-4: Financial Budget

The following parts were chosen based on the proposed design of the Quadcopter prototype. Most of these parts were hard to obtain locally and had to be ordered from an overseas vendor which led to inevitable shipping delays in our original project schedule. The schedule was adapted and eventually all parts were received and tested to ensure proper functionality. These components are of high quality and were be able to withstand our rigorous testing process.

The parts chosen, along with their respective manufacturer, vendor and cost information:

Parts	Manufacturer	Vendor	Cost
Arduino Main Board[1]	Arduino	Sparkfun	$30.00
Accelerometer[2]	N/A	Sparkfun	$75.00
Battery[3] (2) with Charger[4]	Zippy	Hobby King	$95.00
Electronic Speed Controller[5] (4)	Turnigy	Hobby King	$40.00
Carbon Fiber Square Tube[6] (2)	N/A	Hobby King	$10.00
Landing Platform[7]	N/A	Hobby King	$4.00
Motors[8] (8)	Tower Pro	Hobby King	$48.00
Propeller Set[9] (8)	N/A	Maxx Products	$16.00
		TOTAL	**$318.00***

*Total does not include tax and shipping costs.

Evidently, the group has exceeded the $250 budget allotted by the Electrical and Computer Engineering Department. This was necessary to ensure that the prototype had all the important features and worked as planned. The group has decided to not ask for reimbursement from the department and will cover the additional cost ourselves.

The group used the apparatus provided by the department to test the prototype and did not have to purchase specialized test equipment.

Tax and shipping costs were omitted from the total value to give a general idea on the worth of the components and funds needed to complete the project. The additional costs amounted to $65.

II-5: Project Schedule

The Gantt Chart used in the EE424 interim report[10] has been updated to mirror the work done on the project since the interim report was submitted. The format of the chart is the same, with the difference being the increase in the amount of days spent on ordering parts, fabrication and testing. This is because the prototype had undergone significant physical damage during testing and spare parts had to be ordered before the testing and calibration process can resume. This has been documented in the weekly progress reports and the Gantt chart has been updated to reflect this matter.

The Gantt chart has allowed the group to keep track of important deadlines and has enabled us to complete this project in a timely manner.

A copy of the Gantt Chart is available in Appendix A.

III: Conclusion

The overall goal of this project was to create a sustainable and flexible platform for an Autonomous Aerial Vehicle (AEV) using a Quadcopter design profile. To this effect, we have completed this requirement and feel the project was a success. The platform which we have created is capable of sustained autonomous flight at a height of 3 feet. While this in essence proves to be short of our ultimate goal, the group is proud to have created a proven and solid platform for later development. Our platform can be outfitted with additional sensors (cameras, IR sensors, wireless technology) to expand the overall usefulness and flexibility the Quadcopter design. The capabilities of this design may prove to be asymptotic in nature, however these may not be realized until proper funding is given and experimental analysis is conducted.

Given the stable platform produced by this group, further research and development can and should be done to improve the functionality of our design. This may be done by a later Senior Design team or by ourselves during our own time and schedule. This project has increased our interests in robotics and autonomous design, knowledge which will serve useful throughout our professional careers. We feel that this form of thinking and engineering will be prevalent in the modern world and beyond as new applications are found which will test the limits of current technologies. The concept and goal of Senior Design growing out of an interest and incorporating the knowledge and skills learned over the undergraduate career, this has been encapsulated in our project. Overall, the group is proud of our accomplishments and has enjoyed working on the fore-front of engineering technology over the extent of our Senior Design coursework.

IV: References

[1] http://www.sparkfun.com/commerce/product_info.php?products_id=666
[2] http://www.sparkfun.com/commerce/product_info.php?products_id=9268
[3] http://www.hobbyking.com/hobbyking/store/uh_viewItem.asp?idProduct=9364
[4] http://www.hobbyking.com/hobbyking/store/uh_viewItem.asp?idProduct=7898
[5] http://www.hobbyking.com/hobbyking/store/uh_viewItem.asp?idProduct=4204
[6] http://www.hobbyking.com/hobbyking/store/uh_viewItem.asp?idProduct=9012
[7] http://www.maxxprod.com/mpi/mpi-29a.html
[8] http://www.hobbyking.com/hobbyking/store/uh_viewItem.asp?idProduct=4321
[9] http://www.hobbyking.com/hobbyking/store/uh_viewItem.asp?idProduct=9535
[10] http://tiger.ece.stevens-tech.edu/09-10/grp5/documentation/Grp5_spring_interim.pdf

V: Appendices

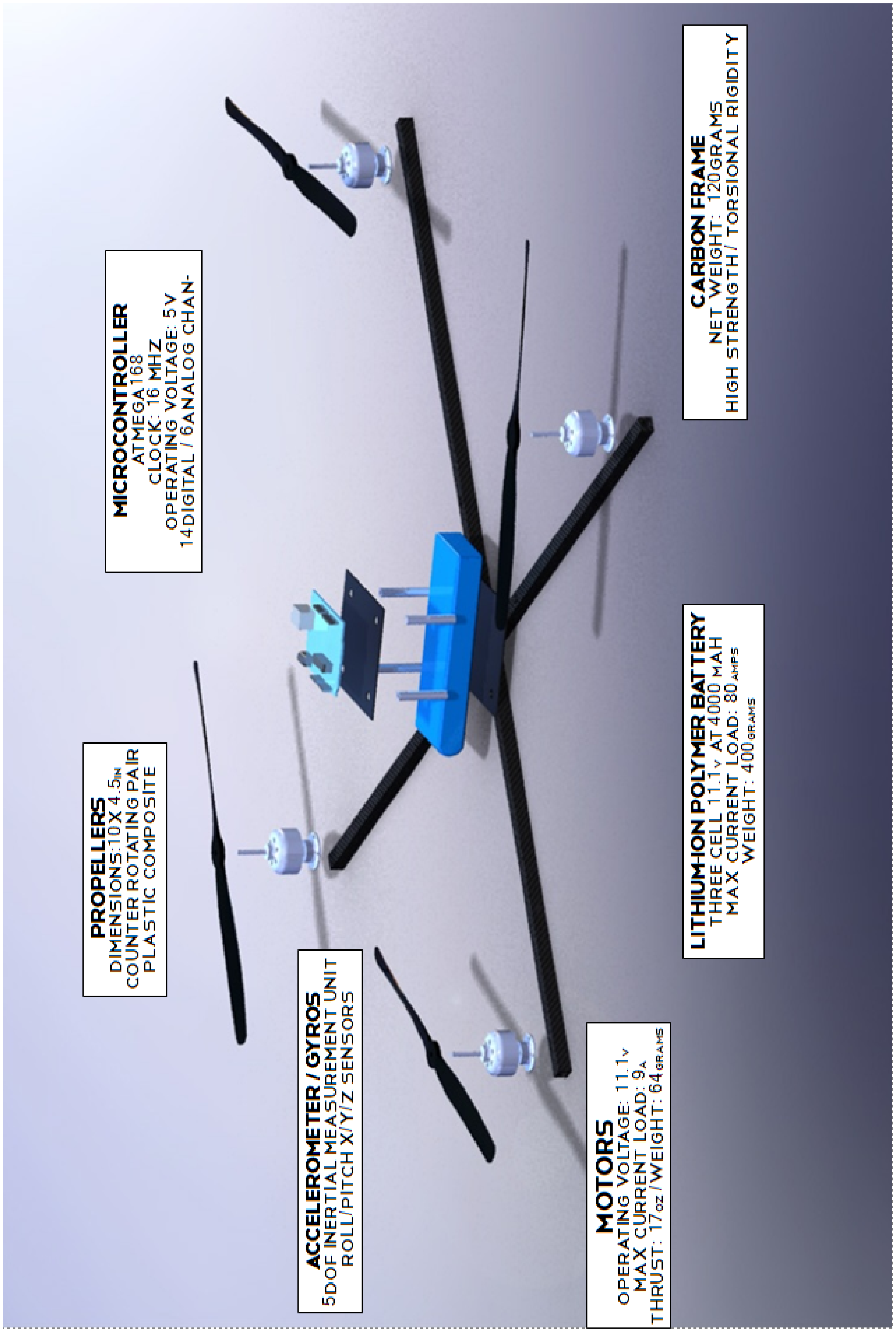
Appendix A: Gantt Chart

EE423 Senior Design	167 days	Tue 9/8/09	Wed 4/28/10
Fall Semester	66 days	Tue 9/8/09	Tue 12/8/09
Proposal of Conceptual De	31 days	Tue 9/8/09	Tue 10/20/09
Select Project Advisor	3 days	Thu 6/18/09	Mon 6/22/09
Define Project Objectives	5 days	Wed 9/16/09	Tue 9/22/09
Define Specifications	6 days	Tue 9/15/09	Tue 9/22/09
Research and Brainstorm	6 days	Tue 9/22/09	Tue 9/29/09
Develop Conceptual Desig	11 days	Tue 9/29/09	Tue 10/13/09
Complete Project Planning	1 day	Tue 10/20/09	Tue 10/20/09
Written Proposal	11 days	Tue 10/6/09	Tue 10/20/09
Technical Analysis	21 days	Tue 10/20/09	Tue 11/17/09
Define and Perform Tachn	6 days	Tue 10/20/09	Tue 10/27/09
Compile and Analyze Resu	11 days	Tue 10/27/09	Tue 11/10/09
Finalize Design Specificati	6 days	Tue 11/10/09	Tue 11/17/09
Group Website	6 days	Fri 11/6/09	Fri 11/13/09
Debugging	6 days	Fri 11/6/09	Fri 11/13/09
Uploading Materials	6 days	Fri 11/6/09	Fri 11/13/09
Overall Analysis of Des	16 days	Tue 11/17/09	Tue 12/8/09
Engineering Design Analys	1 day	Mon 12/7/09	Mon 12/7/09
Plan Prototype	1 day	Tue 12/1/09	Tue 12/1/09
Oral Report	1 day	Tue 12/1/09	Tue 12/1/09
Fall Written Report	36 days	Tue 10/20/09	Tue 12/8/09
EE424 Senior Design	76 days	Tue 1/19/10	Tue 5/4/10
Spring Semester	76 days	Tue 1/19/10	Tue 5/4/10
Build, Debug, Test Proj	1 day	Tue 1/19/10	Tue 1/19/10
Order parts	29 days	Tue 3/9/10	Fri 4/16/10
Assemble PCB	9 days	Tue 1/19/10	Fri 1/29/10
Develop motor controller a	24 days	Tue 1/19/10	Fri 2/19/10
Assemble physical model	19 days	Wed 3/31/10	Mon 4/26/10
Toggle accelerometers/gy	9 days	Wed 4/14/10	Mon 4/26/10
Important Deadlines	76 days	Tue 1/19/10	Tue 5/4/10
Interim Report	11 days	Tue 3/9/10	Tue 3/23/10
Design Day	1 day	Wed 4/28/10	Wed 4/28/10
Final Report	5 days	Wed 4/28/10	Tue 5/4/10

This picture shows the tasks listed on the Gantt Chart from Fall 2009 to Spring 2010.

The highlighted segments represent the tasks that were updated.

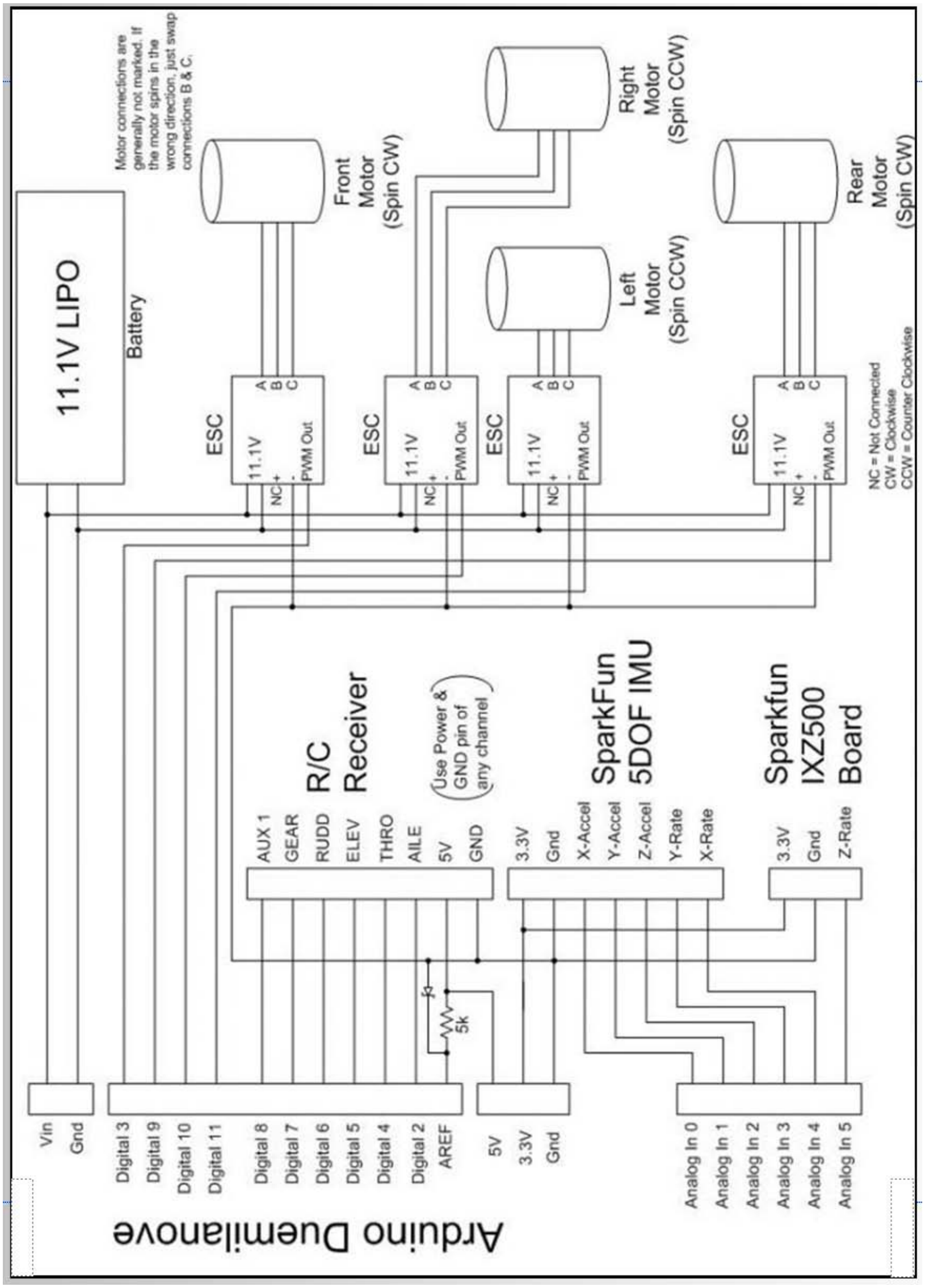
Appendix B:



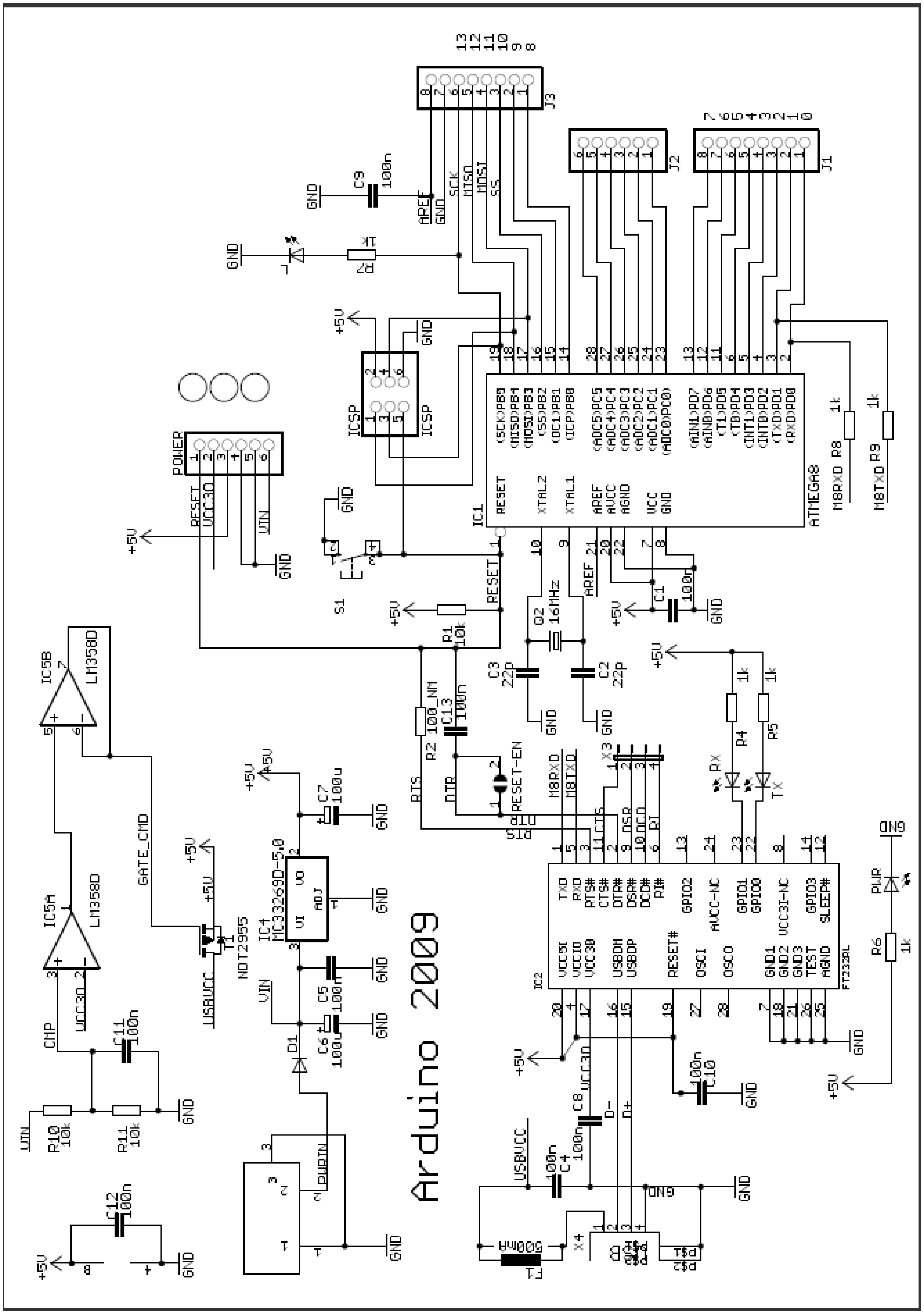
MICROCONTROLLER
ATMEGA168
CLOCK: 16 MHZ
OPERATING VOLTAGE: 5V
14DIGITAL / 6ANALOG CHAN-
CARBON FRAME
NET WEIGHT: 120GRAMS
HIGH STRENGTH/ TORSIONAL RIGIDITY
PROPELLERS
DIMENSIONS:10X4.5IN
COUNTER ROTATING PAIR
PLASTIC COMPOSITE
LITHIUM-ION POLYMER BATTERY
THREE CELL 11.1V AT 4000 MAH
MAX CURRENT LOAD: 80 AMPS
WEIGHT: 400GRAMS
ACCELEROMETER / GYROS
5DOF INERTIAL MEASUREMENT UNIT
ROLL/PITCH X/Y/Z SENSORS
MOTORS
OPERATING VOLTAGE: 11.1V
MAX CURRENT LOAD: 9A
THRUST: 17OZ /WEIGHT: 64GRAMS

Appendix C:

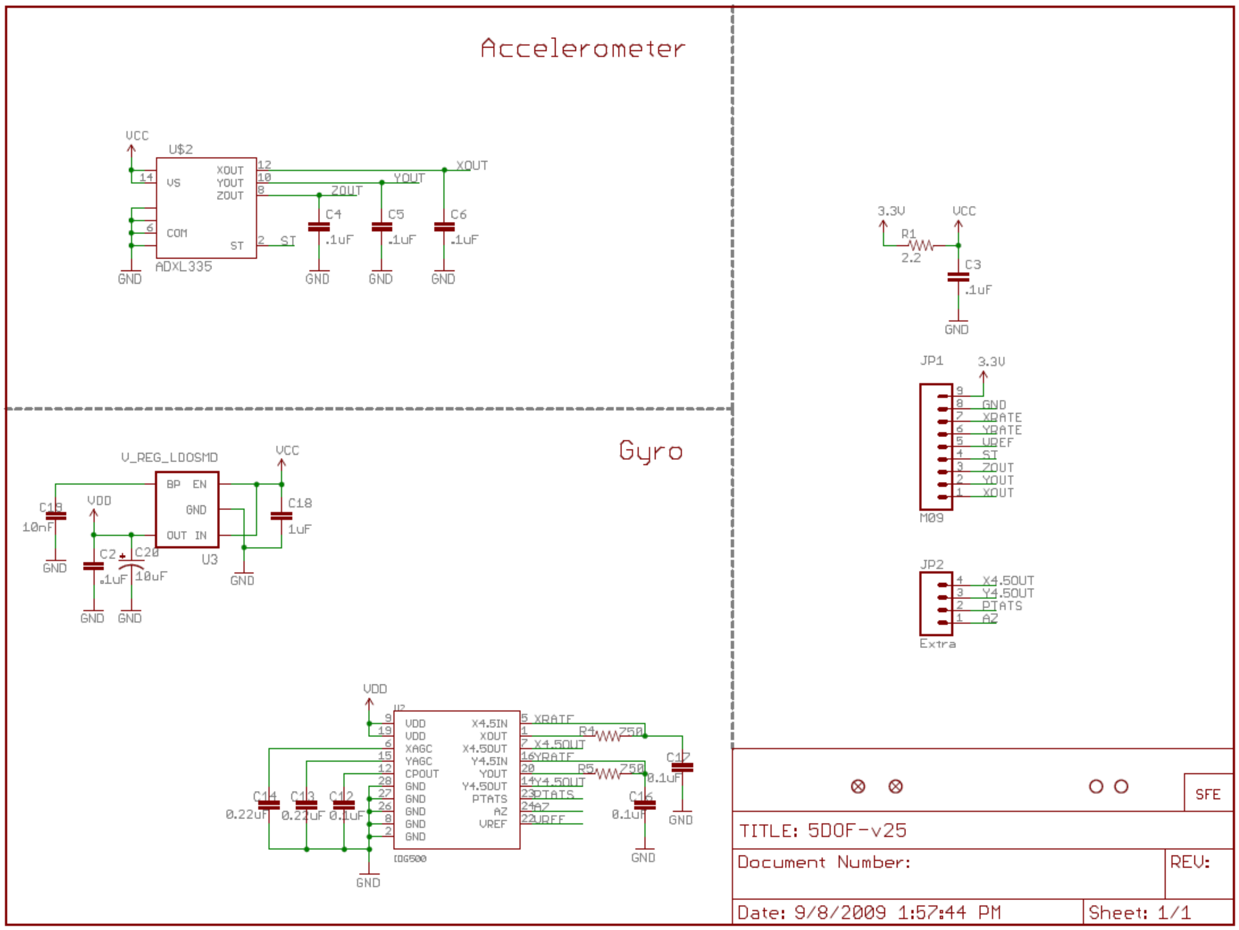
Wiring Diagram



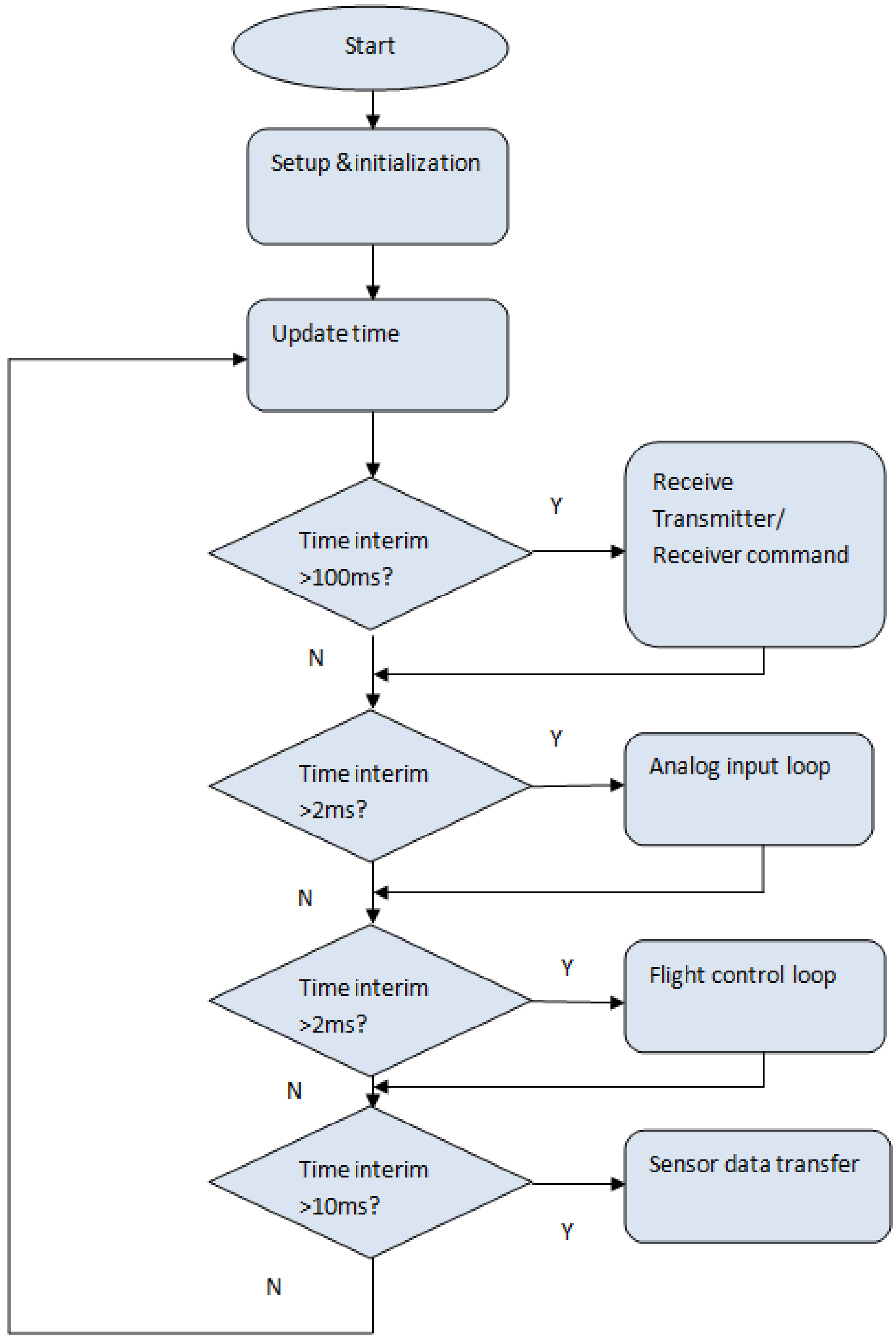
Arduino Schematic:



IMU Schematic:



Software Flow Chart:



Software Architecture: