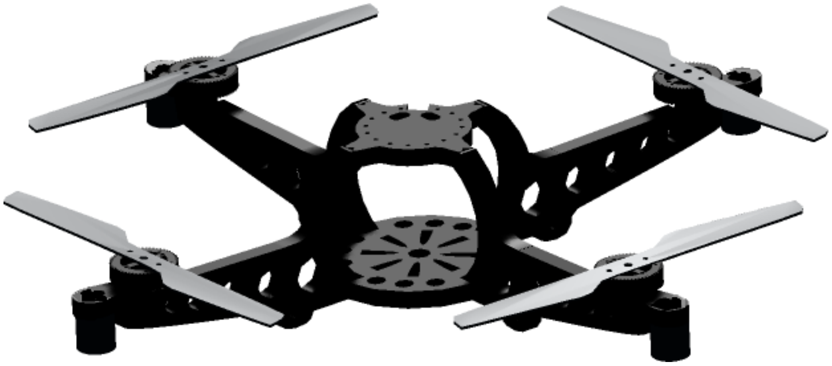
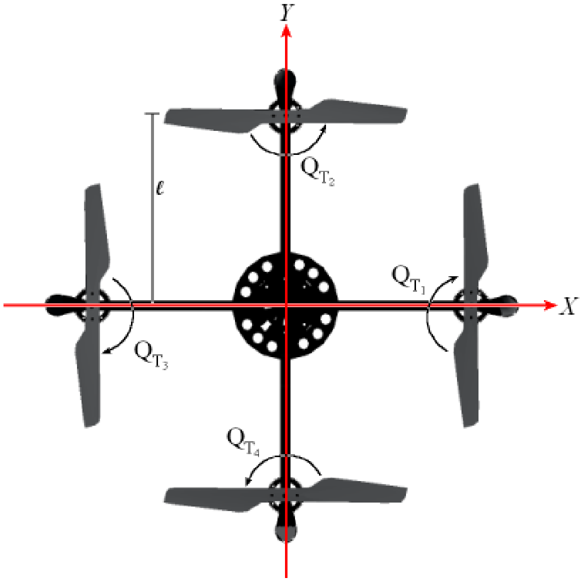
Four Rotor Aerial Platform (FRAP)

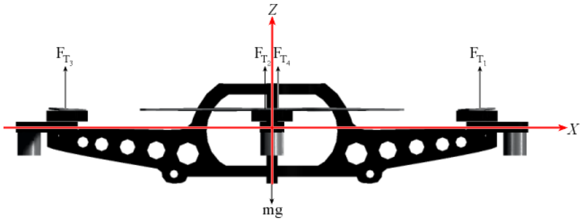
Applications of MEMS
ECE 231

Patrick Mills and Chetan Karani

April 2003







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Outline

Abstract

This paper examines a new hardware control system for an aerial platform utilizing fuzzy logic control. First the platform is reviewed, then its control system is discussed with an emphasis on the microelectromechanical (MEMS) sensors. By using two different types of MEMS sensors, the vehicle is now able to detect both acceleration and angular rotation. With these two signals, the fuzzy logic software control system should be better able to make decisions concerning the platform's current state which should therefore lead to increased stability.

I. Introduction

Unmanned Aerial Vehicles, UAV, facilitate exploration, reconnaissance, and rescue where human presence is difficult, dangerous, or expensive. Helicopters are the most common vehicle used when maneuverability is a primary goal. However, helicopters suffer from a number of drawbacks, one of the biggest being mechanical complexity. A four rotor aerial platform, FRAP, with flight characteristics similar to a helicopter offers reduced design complexity and therefore increased reliability.

The FRAP is controlled by applying forces and generating moments about the three axes: pitch, roll, and yaw. Forward motion is generated by decreasing thrust to the forward rotor while increasing thrust to the rear rotor. Backward motion is generated in an opposite manner. Right and left motion are similar. In order to balance the FRAP, the forward and rear rotors spin in a clockwise direction while the left and right rotors spin in a counter-clockwise direction. The FRAP may be rotated counter-clockwise by increasing thrust to the forward and rear rotors while decreasing thrust to the right and left rotors. A clockwise rotation is created in a similar manner.

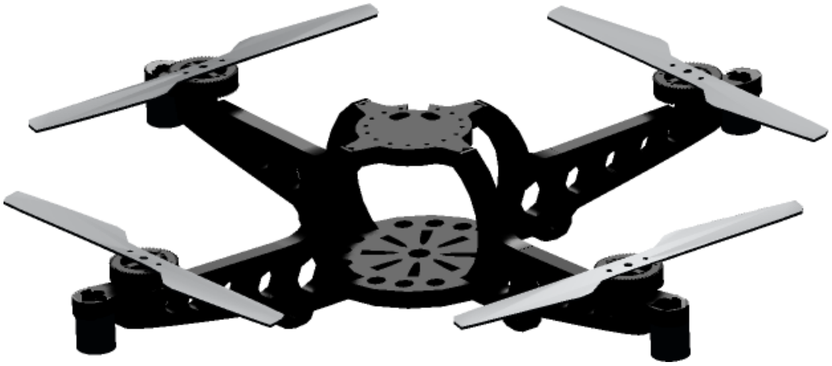

Figure 1: **Four Rotor Aerial Platform**

While a basic helicopter requires a tilting rotor, variable pitch blades, stabilizer fins, and a high speed stabilizer rotor, an FRAP requires only four fixed pitch rotors. Furthermore, control is achieved by varying the velocity of each rotor. This means that complete control of the vehicle can be achieved with four controls: move up / down, move forward / reverse, move left / right, rotate clockwise / counter-clockwise. Although the FRAP's control system is quite simple, the platform's flight dynamics are intrinsically unstable. A discussion of the platform model and dynamics can be found in Mills [4].

Basically, the platform is a three dimensional inverted pendulum. Fuzzy logic is very good at dealing with non-linear control problems. However, in order to stable the platform, the control logic must know what is happening in the physical world. Two types of sensors provide information about the platform's dynamics: accelerometers and rate gyroscopes. The accelerometers measure the acceleration in a particular direction while the gyroscopes measure angular velocity.

Using these sensors the control logic is capable of gathering enough information to stabilize the platform during flight. The rest of this paper discusses the new hardware control system.

II. System Block Diagram

The system consists of 5 major sections : the microcontroller, remote control receiver, two sensor types, power source and conditioning, and motor drivers and motors. Current conditions are displayed using the LEDs. The various sections are expanded in the list below and a system block diagram is shown below.

- Microcontroller
- Power
- Power Regulator
- R/C Receiver
- Status Indicator
- Motor Driver & Motors
- Location / Orientation
    - Accelerometers
    - Rate Sensors / Gyroscopes
- PCB

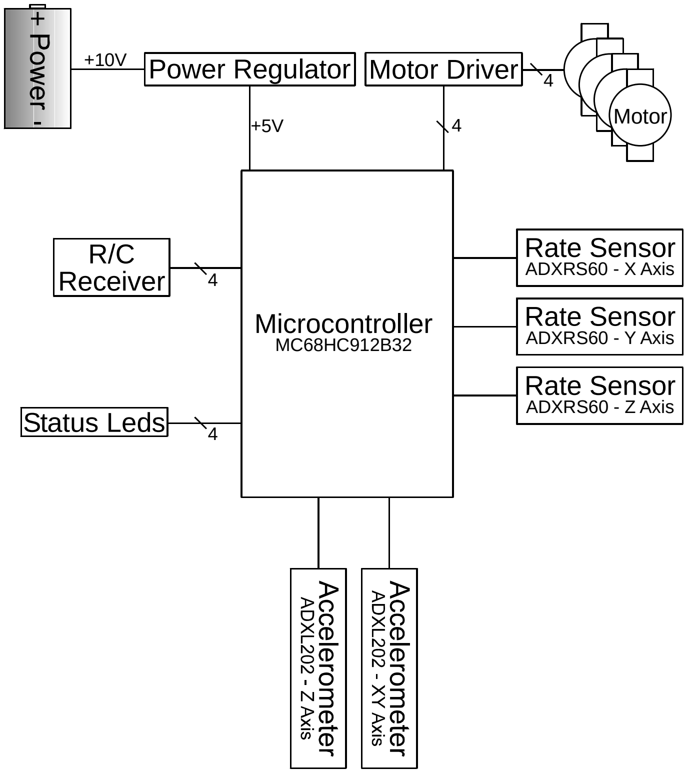

Figure 2: **System Block Diagram**

III. Sensors and Interface Electronics

The FRAP utilizes two types of MEMS sensors to “view” the external world. The first type is the Analog Devices ADXL202 Dual-Axis Accelerometer. This device is a polysilicon surface-micromachined sensor with onboard signal conditioning circuitry. The sensor can measure both positive and negative acceleration to ±2 g.

In this implementation, the accelerometer is being used as a tilt-sensor; in this configuration, the static acceleration force of gravity is utilized to excite the sensor. The output of the sensor is a duty cycle offering 14-bit precision.

This sensor was chosen do to its precision and reliability as well as the ease of integrating the sensor with the microcontroller. Since conditioning circuitry is contained on the sensor IC, the output can be directly connected to the microcontroller.

There are three main considerations when integrating the ADXL202 into a system which utilizes the chips duty cycle output. First, it is important to set the duty cycle period, T_2. This setting determines the number of samples per second or bandwidth of the sensor.

$$T_2 = \frac{R_{SET}(\Omega)}{125M\Omega}$$

The MC68HC912B32 has a timer with 16-bit resolution. The Input Capture feature allows asynchronous timing calculations to be performed on any of eight specific port pins. With an input crystal frequency of 16 MHz, the E clock is 8 MHz, which is 125 ns/clock. With a 16-bit resolution, there are 65536 ticks which provides a maximum period of 8 ms. Setting the ADXL202 to utilize a T_2 duty cycle of 8 ms provides the maximum sensor resolution; R_{SET} = 1 MΩ.

Due to Nyquist limit, we need sensor frequency ≤ ½ microcontroller sample frequency to avoid sensor aliasing. With a period of 8 ms, the microcontroller sample frequency is 125 Hz which means the sensor frequency must be ≈ 60 Hz or less.

$$F_{-3dB} = \frac{5\mu F}{C_{(X,Y)}}$$

Setting $C_X = C_Y = 0.1\mu F$ gives a sensor bandwidth of 50 Hz which satisfies our requirements.

The RMS Noise with a bandwidth setting of 50 Hz is 1.8 mg with a Peak-to-Peak Noise of 7.2 mg.

Since T_2 = 8 ms, the ADXL202 sample rate is 125 Hz. Since the sensor has a resolution of ±2 g, we have a range of 4 g; however, we need two samples to measure the 50 Hz signal, so there are 8192 microcontroller timer counts/g or a resolution of 122µg (0.1mg).

This resolution is completely drowned by our noise floor, so the maximum resolution will be limited to 1.8 mg.

A measurement of ½ duty cycle is equal to 0 g. The acceleration can be calculated using the following formula:

$$a = \frac{T_1 / T_2 - 0.5}{0.125} = 8\frac{T_1}{T_2} - 4 \quad \text{where } T_1 \text{ is an actual timer count and } T_2 = 65536$$

Several initial readings are taken during system initialization which are used to null adjust the sensor output. Null adjusting is a simple process where the difference between a 50% duty cycle or 32768 clock counts and the average readings from a level and resting sensor are stored and used as an offset for all future sensor readings. The ADXL202 is temperature sensitive, and future upgrades may utilize the PTAT temperature sensor in the ADXRS60 to neutralize long term sensor drift.

The second type of sensor is the Analog Devices ADXRS ±60°/s single chip rate gyroscope. This device is a polysilicon surface-micromachined sensor with onboard signal conditioning circuitry. The sensor can measure both positive and negative angular rate to ±60°/s.

The ADXRS60 measures the Coriolis acceleration induced by angular rate. The output is a voltage proportional to angular rate.

The MC68HC912B32 has 8 10-bit Analog-to-Digital input ports. With a 16 MHz crystal, a 10-bit A/D conversion takes 20 clocks for a maximum frequency of 2 MHz. However, the 6812 can only sample one of its eight A/D channels at a time. In the continuous mode setting, the microcontroller cycles through 4 or 8 channels continuously. This means that the maximum sample rate is 2 MHz / 4 or 2 MHz / 8 * 1/20 clocks. To allow for future expansion, it was decided to make the microcontroller cycle through all eight A/D channels which gives a sample rate of 12.5 KHz.

Due to Nyquist limit, we need sensor frequency ≤ ½ microcontroller sample frequency to avoid sensor aliasing. Since the microcontroller sample frequency is 12.5 KHz, the maximum sensor frequency is 6250 Hz. This is too high for our needs, and the sensor is instead low-pass filtered to 40 Hz by selecting C_{out} capacitance of 22 nF.

To conserve microcontroller power, the processor sampling frequency can be reduced by adjusting the ATD control register. While it would be optimal to sample the four A/D channels at 80 Hz, that is not possible; instead the sample rate can be reduced from 6250 Hz to 1800 Hz.

The ADXRS60 is extremely easy to calibrate. Several initial readings are taken during system initialization which are used to null adjust the sensor output. Null adjusting is a simple process where the difference between a reading of 2.5 V and the average readings from a resting sensor are stored and used as an offset for all future sensor readings.

IV. Microcontroller

The MC68HC912B32 microcontroller was chosen due to its compact design, extreme flexibility, available ports, and simple implementation. The 6812 requires a minimum of external electronics, consisting mainly of resistors, capacitors, and a clock.

The MC68HC912B32 microcontroller has the following features:

- 16-bit CPU
    - Upwardly compatible with the MC68HC811
    - 20-bit ALU
    - Fuzzy Logic Instructions
    - 8 MHz clock
- 32 KB Flash EEPROM
- 1 KB RAM
- 768 B EEPROM
- 8-channel, 10-bit A/D
- 8-channel Timer module
    - Supports both Input Capture and Output Compare
    - Simple Pulse-Width Modulator
- 16-bit Pulse accumulator
- Pulse-width modulator (PWM)
    - 8-bit, 4-channel or 16-bit, 2-channel
    - Separate control for each pulse width and duty cycle
    - Programmable center-aligned or left-aligned outputs
- Asynchronous Serial Interface
- COP watchdog timer
- 63 general-purpose I/O pins

In particular, the FRAP design utilizes the A/D converter, Input Capture, Serial Interface, and PWM module. The fuzzy logic instructions also simplify the software control system.

The previous version of the FRAP was implemented using the MC68HC811E2 microcontroller. The design was limited by the 2 MHz clock, 8-bit CPU, limited addressing modes, limited RAM, and the time taken to implement the software control system. The new design offers the space and time to implement a much more complex software control system.

Both the ADXL202 and the ADXRS60 have simple null adjust calibrations; the 6812 is able to handle these adjustments in real-time.

The only real complication with the 6812 is that it does not come with a bootloader in ROM. However, utilizing J7 pin 1, the Background Debug Mode (BDM) can be used to install a bootloader in a special section of the Flash EEPROM (J7 pin 2 must be used to provide a stable +12V power supply while reprogramming the Flash). Once installed, the data jack can be used to reprogram the EEPROM dynamically without a need for external power. The data jack uses a serial DB9 to 2.5mm stereo audio jack cable produced by Apple for its Macintosh series; this allows the required footprint on the PCB to be quite small while still providing the flexibility to serially link to the microcontroller.

V. Communications

The FRAP can be operated in either autonomous mode or in remote controlled mode. However, without a GPS and/or micro-camera, the autonomous mode equates to flying blind.

The remote control uses a standard R/C transmitter operating at 72.470 MHz (channel 34). The receiver is a Futaba FP-R127DF FM seven channel duty cycle receiver with a 20 KHz narrow band. A similar process to decoding the ADXL202 duty cycle is used for the receiver outputs.

An initial calibration is used to measure the null adjust parameters for each channel. Four 6812 Input Capture ports are used to measure the duty cycle and convert to scaled input values representing the speed, pitch, roll, and yaw.

This subsystem was developed for the previous version of the FRAP and easy to implement and provides reliable results, no changes were made in this version.

VI. Power Source

The power source consists of eight 1.2 volt Sanyo Cadnica Extra (KR-600AE) ⅔ AA Nickel Cadmium cells connected in series. The battery pack provides approximately 9.6 volts at 600 mA/Hr.

The major power drain comes from the four rotor motors; standard flight time is approximately 5 minutes. When connected to a PC, the battery can sustain the microcontroller for several hours; programming the EEPROM creates an additional power drain – the EEPROM can be reprogrammed approximately 5 times per battery charge over the course of several hours.

VII. System Schematic

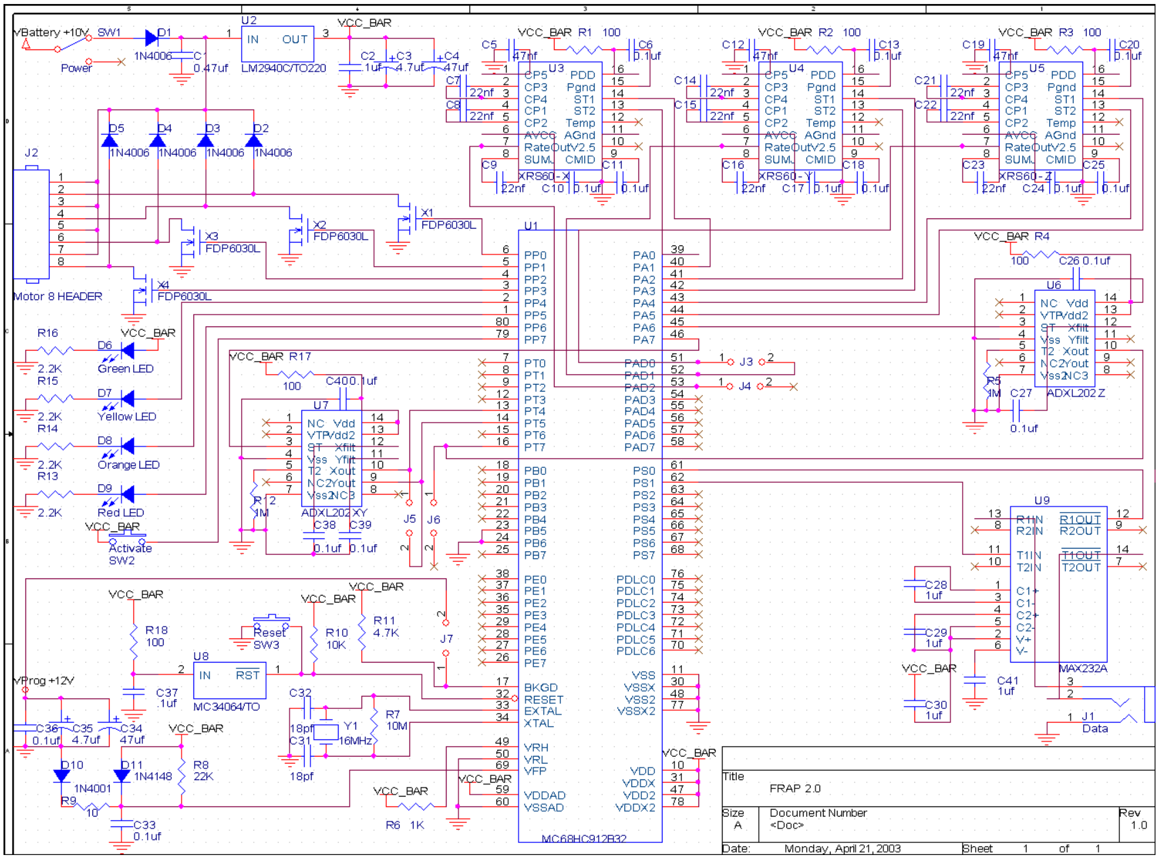

Figure 3: **System Schematic**

The System Schematic is very straight forward. The only non-standard component is the Flash programming voltage (VFP) which must be kept just below VDD in normal mode and just below +12V when reprogramming. The microcontroller is easily damaged should the VFP voltage drop below VDD – 0.35V. A special RC circuit provides VDD – 0.35V whenever the +12V programming voltage is not applied.

VIII. PCB Layout

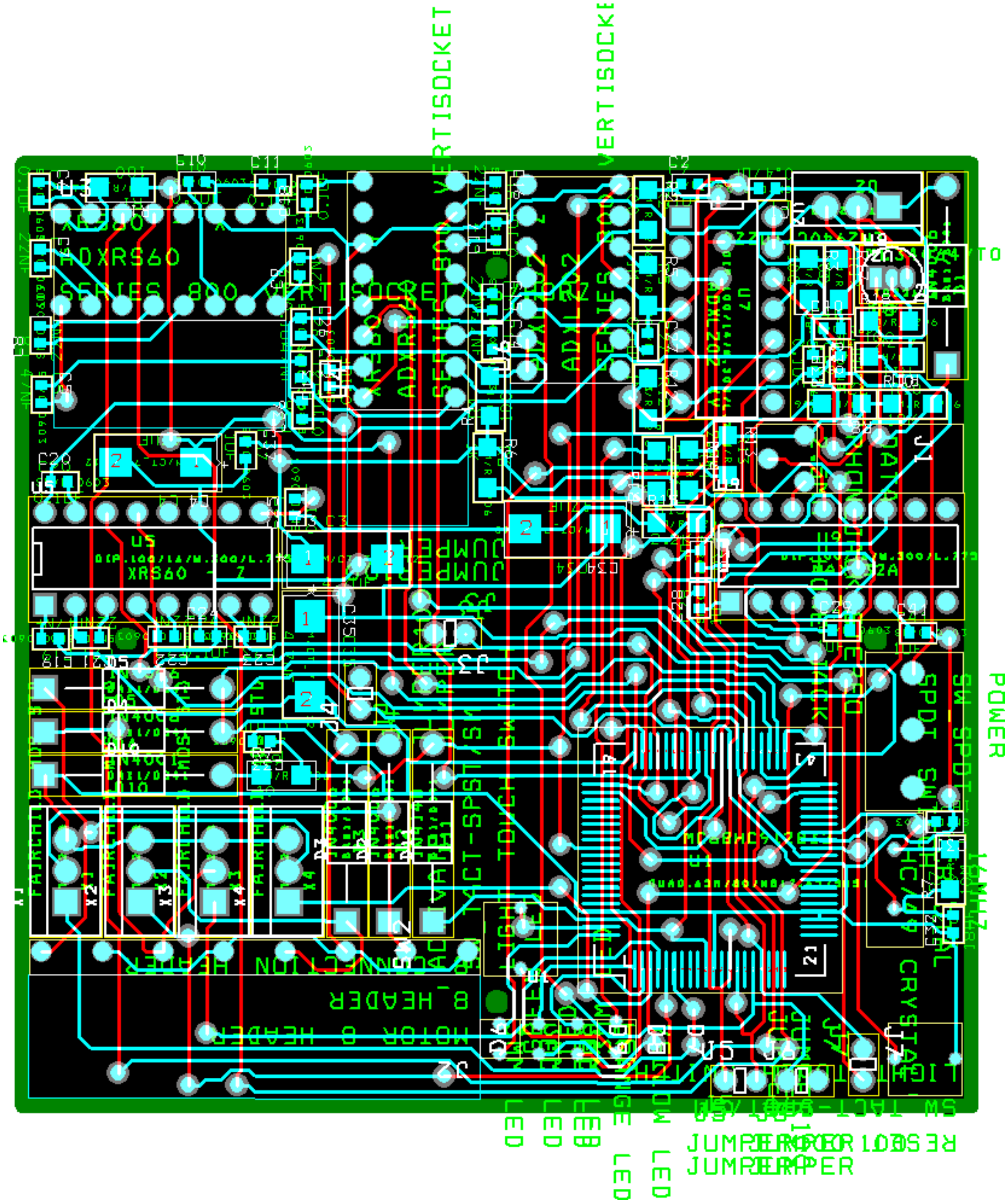

Figure 4: **PCB Layout**

The FRAP frame has space for a maximum board size of 78mm x 78mm. It was quite a challenge to have a two sided board with no jumpers. The original design included many extra jumpers for future expansion and easy testing of the microprocessor; however, these had to be removed to complete routing. All jumpers to sensors were kept.

Shown actual size (78 mm x 78 mm)

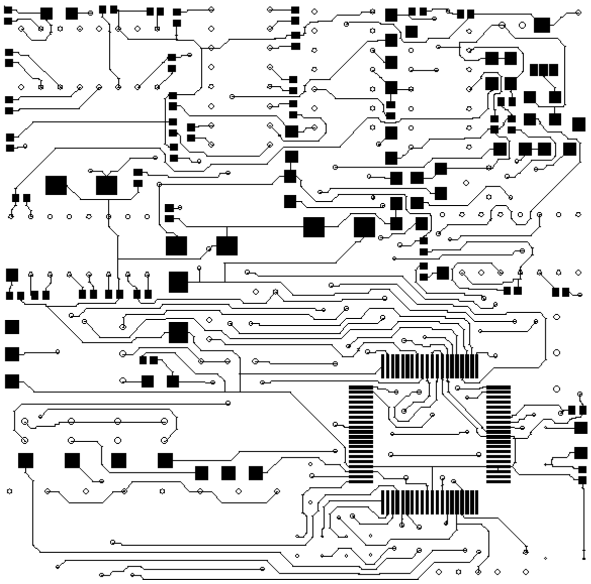

Figure 5: **PCB Top**

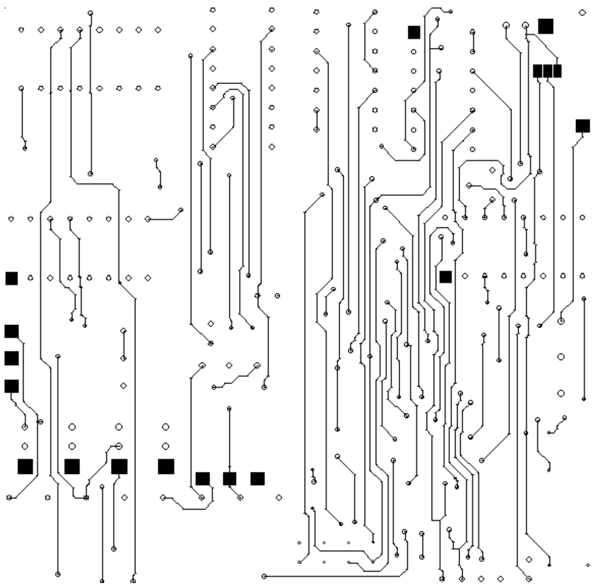

Figure 6: **PCB Bottom**

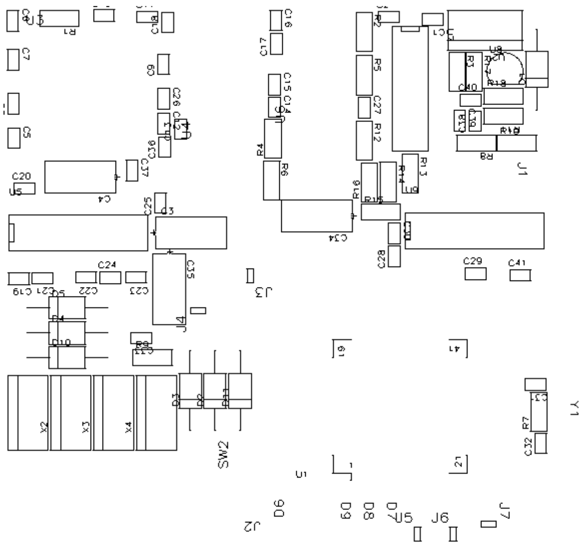

Figure 7: **PCB Silkscreen**

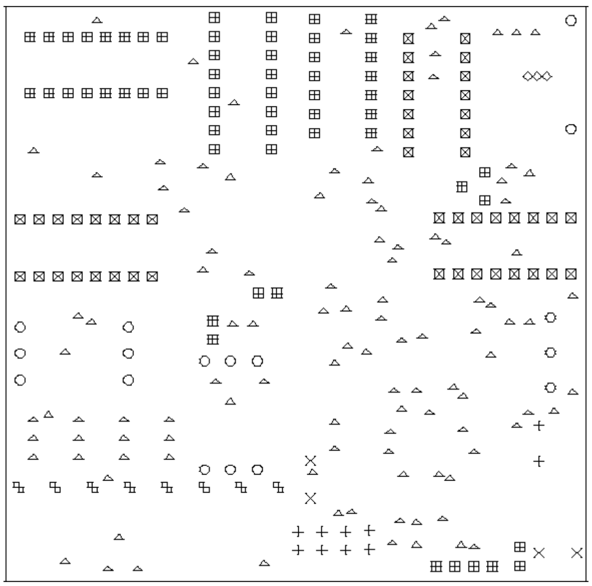

Figure 8: **PCB Drill Chart**

Parts List

Name	Description	Footprint	Part(s)
MC68HC912B32	Microcontroller	QFP 80 QUAD.65M/80/WG17.45/SMS1	U1
LM2940C	+5V Voltage Regulator	TO-220 TO-220AB	U2
ADXRS60	X-axis 60° Angular Acceleration	DIP-16 DIP.100/16/W.300/L.775	U3
ADXRS60	Y-axis 60° Angular Acceleration	DIP-16 – horizontal	U4
ADXRS60	Z-axis 60° Angular Acceleration	DIP-16 – vertical	U5
ADXL202	XY-axis Accelerometer	DIP-14 DIP.100/14/W.300/L.700	U6
ADXL202	Z-axis Accelerometer	DIP-14 – vertical	U7
MC34064	Undervoltage Sensing circuit	TO-226 TO-226AA	U8
FDP6030L	Transistor-Level MOSFET	TO-220	X1, X2, X3, X4
1N4006	Diode	DO-41	D1-D5
LED	Green, Yellow, Orange, Red LED	3nn	D6-D9
1N4001	Diode	DO-41	D10
1N4148	Diode	DO-35	D11
Data Jack	2.5 mm Stereo Audio Jack		J1
8 Connection Header	Motor 8-pin Header		J2
Pin Header	2x1 Output Header		J3-J7
Crystal	16 MHz (HC-49 Series)		Y1
SPDT	Switch		SW1
Toggle	Light Touch Push Button		SW2-SW3
18 pF	Ceramic Capacitor (50V)	0603	C31, C32
0.022 µF	Ceramic Capacitor (16V)	0603	C7, C8, C9, C14, C15, C16, C21, C22, C23
0.047 µF	Ceramic Capacitor (50V)	0603	C5, C12, C19
0.1 µF	Ceramic Capacitor (16V)	0603	C6, C10, C11, C13, C17, C18, C20, C24, C25, C26, C27, C33, C36, C37, C38, C39, C40
0.47 µF	Ceramic Capacitor (16V)	0603	C1
1.0 µF	Ceramic Capacitor (16V)	0603	C2, C28, C29, C30, C41
4.7 µF	Electrolytic Capacitor (25V)	SMD-SMT	C3, C35
47 µF	Electrolytic Capacitor (25V)	SMD-SMT	C4, C34
10 Ω	Resistor (1/4 W)	1206	R9
100 Ω	Resistor (1/4 W)	1206	R1, R2, R3, R4, R17, R18
1K Ω	Resistor (1/4 W)	1206	R6
2.2K Ω	Resistor (1/4 W)	1206	R13, R14, R15, R16
4.7K Ω	Resistor (1/4 W)	1206	R11
10K Ω	Resistor (1/4 W)	1206	R10
22K Ω	Resistor (1/4 W)	1206	R8
1M Ω	Resistor (1/4 W)	1206	R5
10M Ω	Resistor (1/4 W)	1206	R7, R12

IX. Work Summary

The project consisted of creating a PCB board with no jumpers that integrated all electronics on a single two sided board. At this time there are no outstanding problems.

The board provides a reliable and stable platform for the microcontroller and the MEMS sensors. Care was taken to minimize distances between power filters and components, and to ensure that power routes were minimal and that no loops were in the final routes.

X. Future Directions

While no serious problems are anticipated with the current design, some upgrades could provide better performance. For example, battery life is always a prime consideration. The major battery limit are the 4 motors; switching from a NiCAD to a NiMH or LiOn battery source might provide more flying time.

The overall PCB complexity could be reduced by utilizing a 3D accelerometer. Analog Devices made one in the past, the ADXL105-3, but it has been deprecated. Other companies are offering such solutions. A multi-axis gyroscope would also be extremely useful.

To help correct for temperature errors in the ADXL202 readings, the PTAT temperature sensor from the ADXRS60 could be used.

A GPS receiver could be used to determine actual position in 3D. This could be augmented with a micro-camera to allow for full autonomous mode operation.

References

[1] G. Erikson. Application of inertial sensing to handheld terminals. Ericsson Radio Systems. Department of Teleinformatics, December 2001.

[2] B. Miller and A. Qaiyumi. Holly: An Autonomous Air Cushion Vehicle. University of Florida, Department of Electrical Engineering Intelligent Machines Design Laboratory, December 1996.

[4] T. Liu. Interfacing of A Tilt Sensor to Personal Digital Assistant. Thesis, Department of Information Technology and Electrical Engineering, University of Queensland, October 2001.

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[7] P. Shih and H. Weinberg. A Useful Role for the ADXL202 Dual-Axis Accelerometer in Speedometer-Independent Car-Navigation Systems. *Analog Dialog*, v. 35-4, 2001.

[8] M. Shuster, etc al. Mounting Considerations for ADXL Series Accelerometers. Application Note AN-379. Analog Devices.

Appendix A: Sensor Data Sheets

Selected parts of the data sheets from sensors used in the system are included here. The following parts are shown:

- Analog Devices ADXL202
    - General Description
    - Specifications
    - Pin Assignment
    - Theory of Operation
    - Design Procedure
    - Microcontroller Interface
    - Noise Calculation
    - Calibration
    - Standard Timer Module with Block Diagram
    - Analog-to-Digital Converter with Block Diagram
    - Electrical Specifications
    - Mechanical Specifications

- Analog Devices ADXRS60
    - General Description
    - Specifications
    - Pin Assignment
    - Bandwidth Selection
    - Self Test

Appendix B: Electronics Data Sheets

Selected parts of the data sheets from parts used in the system are included here. The following parts are shown:

- MC68HC912B32 – microcontroller
    - Features
    - Microcontroller Block Diagram
    - Pin Assignments
    - Basic Schematic
    - Flash EEPROM
    - Clock Generation Module
    - Pulse-Width Modulator (PWM)
    - Standard Timer Module with Block Diagram
    - Analog-to-Digital Converter with Block Diagram
    - Electrical Specifications
    - Mechanical Specifications

- 16 MHz HC/49 Series Crystal
    - Electrical Specifications
    - Mechanical/Environmental Specifications

- FDP6030L – MOSFET
    - Pin Assignments
    - Electrical Specifications

- LM2940 – 1A Low Dropout Regulator
    - Pin Assignments
    - Electrical Specifications
    - Performance Characteristics
    - Applications Hints
    - Mechanical Specifications

- LX30441 – LED
    - Pin Assignments
    - Mechanical Specifications
    - Electro-Optical Specifications

- NKK Series M Toggle Switch – SPDT Switch
    - Electrical Specifications
    - Pin Assignments
    - Mechanical Specifications

- EVQ11 - Light Touch Switch
    - Electrical Specifications
    - Mechanical Specifications

- PCB Header
    - Mechanical Specifications

- 2.5 mm Stereo Phone Jack
    - Mechanical Specifications

- Series 800 Vertisocket – Vertical Mounting
    - Mechanical Specifications

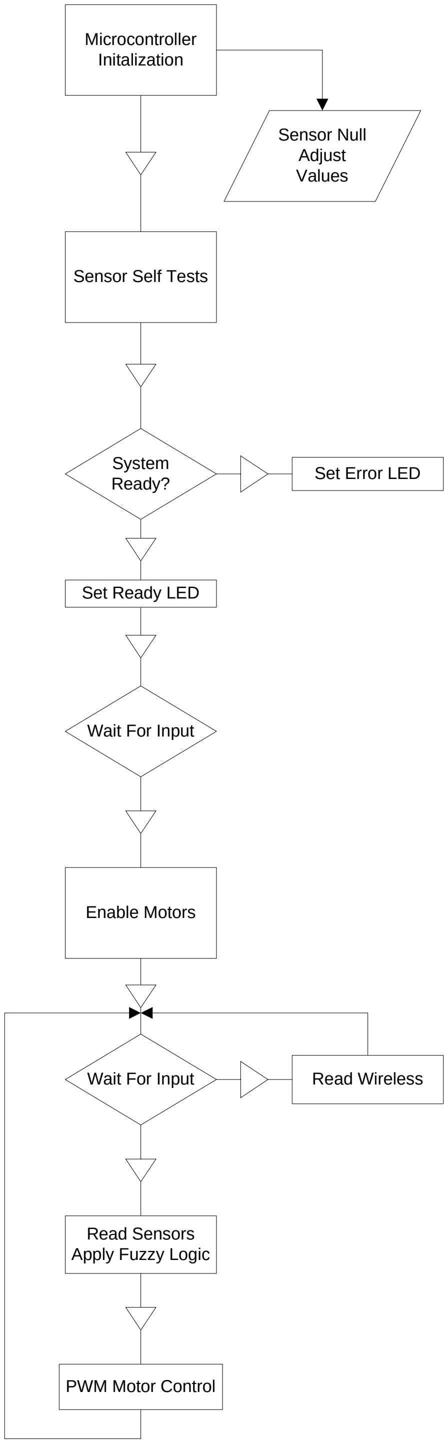
- Diodes – 1N4148 / 1N4001 – 1N4007
    - Electrical Specifications
    - Mechanical Specifications
    - Performance Characteristics

- Thin Film SMT Resistors
    - Electrical Specifications
    - Mechanical Specifications

- SMT Aluminum Electrolytic Capacitor
    - Mechanical Specifications

- SMT Ceramic Chip Capacitor
    - Electrical Specifications
    - Mechanical Specifications

Appendix C. Microcontroller Program Flow Diagram



Configure Memory Layout, ports, perform startup tests, take initial sensor readings

Store Sensor Null Adjust Values

Test Sensors

Wait for Enable Push Button

Wait for Wireless Control Inputs

Read Sensor Values, Apply Control System

Update PWM parameters

Program Serial Bootloader

(Code removed, please contact the Author for more information.)

Program Memory Dump

(Code removed, please contact the Author for more information.)

Program Control Logic

(Code removed, please contact the Author for more information.)

Appendix D: OrCAD Schematic and Layout

The following pages show the detailed schematic and PCB layout. The PCB board is a 78 mm x 78 mm double sided board. The design requires no jumper cables.

FRAP Specifications:

1. FRAP is controlled by applying forces and generating moments about the three axes: Pitch, Roll and Yaw. FRAP has reduced design complexities and therefore increased reliability.

2. System Requirements:
    - 4 Input Capture ports for R/C receiver duty-cycle measurement
    - 3 Input Capture ports for Accelerometer duty-cycle measurement
    - 3 A/D channels for Gyroscope measurement
    - 4 PWM ports
    - PCB 78mm x 78 mm, dual sided board, front side components only, no jumpers

3. FRAP features:
    - CPU controlled system
    - High Quality 7 channel FM transmitter
    - Durable Lightweight carbon fiber body
    - 4 high speed Electric motors with rotor blades
    - 9.6 V 600 mA/Hr NiCAD battery providing 5 minutes flight

4. Software:

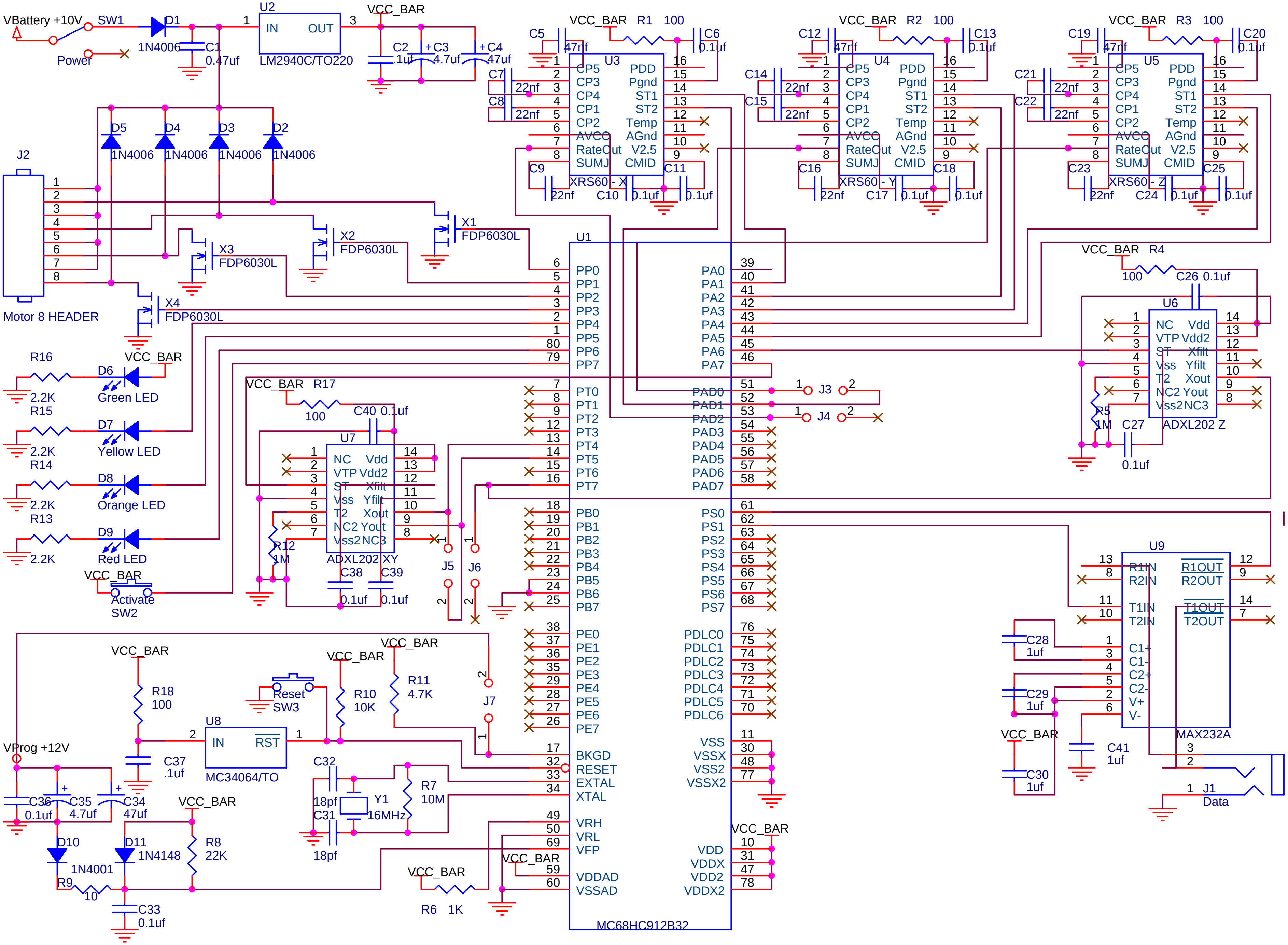
Product	**Feature**
AS12 Assmembler	
Cadence PSD 14.0	Integrated to for: Schematic drawing (Capture CIS) Layout drawing (Layout Plus)

By connecting long cord from the FRAP to a motorcycle battery longer fly times. This limits the flying area.

5. Max Payload weight: 100 grams
   The load carrying capacity depends upon a lot of factors such as altitude above sea level, the battery weight, how well the blades are sanded, etc.

6. Physical Specs:

Features	Specification
Height	110 mm
Width	560 mm
Depth	560mm
Weight (Net)	650 grams


VBattery +10V
SW1
Power
D1
1N4006
C1
0.47uf
U2
IN
OUT
LM2940C/TO220
VCC_BAR
C2
.1uf
C3
4.7uf
C4
47uf
D5
D4
D3
D2
1N4006
J2
Motor 8 HEADER
X1
X2
X3
X4
FDP6030L
VCC_BAR
R1
100
C5
47nf
C6
0.1uf
C7
C8
22nf
U3
CP5
CP3
CP4
CP1
CP2
AVCC
RateOut
SUMJ
PDD
Pgnd
ST1
ST2
Temp
AGnd
V2.5
CMID
C9
22nf
XRS60 - X
C10
0.1uf
C11
0.1uf
R2
C12
C13
C14
C15
U4
C16
XRS60 - Y
C17
C18
R3
C19
C20
C21
C22
U5
C23
XRS60 - Z
C24
C25
U1
PP0
PP1
PP2
PP3
PP4
PP5
PP6
PP7
PT0
PT1
PT2
PT3
PT4
PT5
PT6
PT7
PB0
PB1
PB2
PB3
PB4
PB5
PB6
PB7
PE0
PE1
PE2
PE3
PE4
PE5
PE6
PE7
BKGD
RESET
EXTAL
XTAL
VRH
VRL
VFP
VDDAD
VSSAD
PA0
PA1
PA2
PA3
PA4
PA5
PA6
PA7
PAD0
PAD1
PAD2
PAD3
PAD4
PAD5
PAD6
PAD7
PS0
PS1
PS2
PS3
PS4
PS5
PS6
PS7
PDLC0
PDLC1
PDLC2
PDLC3
PDLC4
PDLC5
PDLC6
VSS
VSSX
VSS2
VSSX2
VDD
VDDX
VDD2
VDDX2
MC68HC912B32
J3
J4
VCC_BAR
R4
100
C26
0.1uf
U6
NC
VTP
ST
Vss
T2
NC2
Vss2
Vdd
Vdd2
Xfilt
Yfilt
Xout
Yout
NC3
ADXL202 Z
R5
1M
C27
0.1uf
R16
VCC_BAR
D6
2.2K
Green LED
R15
D7
Yellow LED
R14
D8
Orange LED
R13
D9
Red LED
VCC_BAR
R17
100
C40
0.1uf
U7
ADXL202 XY
R12
1M
C38
0.1uf
C39
0.1uf
J5
J6
VCC_BAR
Activate
SW2
U9
R1IN
R2IN
T1IN
T2IN
C1+
C1-
C2+
C2-
V+
V-
R1OUT
R2OUT
T1OUT
T2OUT
MAX232A
C28
1uf
C29
1uf
VCC_BAR
C30
1uf
C41
1uf
J1
Data
VCC_BAR
R18
100
U8
IN
RST
MC34064/TO
C37
.1uf
Reset
SW3
VCC_BAR
R10
10K
VCC_BAR
R11
4.7K
J7
C32
18pf
C31
18pf
Y1
16MHz
R7
10M
VProg +12V
C36
0.1uf
C35
4.7uf
C34
47uf
VCC_BAR
R8
22K
D10
1N4001
D11
1N4148
R9
10
C33
0.1uf
VCC_BAR
R6
1K
VCC_BAR
VCC_BAR