CRIM Surya University: Flapping bird robot project
Electrical and Electronics Specifications

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December 30, 2013

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Contents

1 Introduction

This document presents electrical and electronics specifications for the flapping bird robot (ornithopter) project. The high level block diagram of the proposed system is shown in figure 1.

We remark that the best reference model thus far is the SmartBird project from FESTO, which was revealed in 2011. Other noticeble projects include the Big Bird Robo Raven (University of Maryland), the RoboSwift (Delft University of Technology) and the Bat robots (Brown University). Besides, some (toy) ornithopter products are worth attention, such as WowWee Flytech Dragonfly, Cybird 2-Channel RC Ornithopter and E-Bird Flapping-Wing Aircraft R/C Flying Robot and Avitron V2.0.

2 Management

2.1 Work Breakdown Structure

1. Electronics
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      iii. Curvy flight
      iv. Gliding flight
3. Closure
   (a) Demonstrations
   (b) Reports

2.2 Schedule

The timeline is shown in table 1.

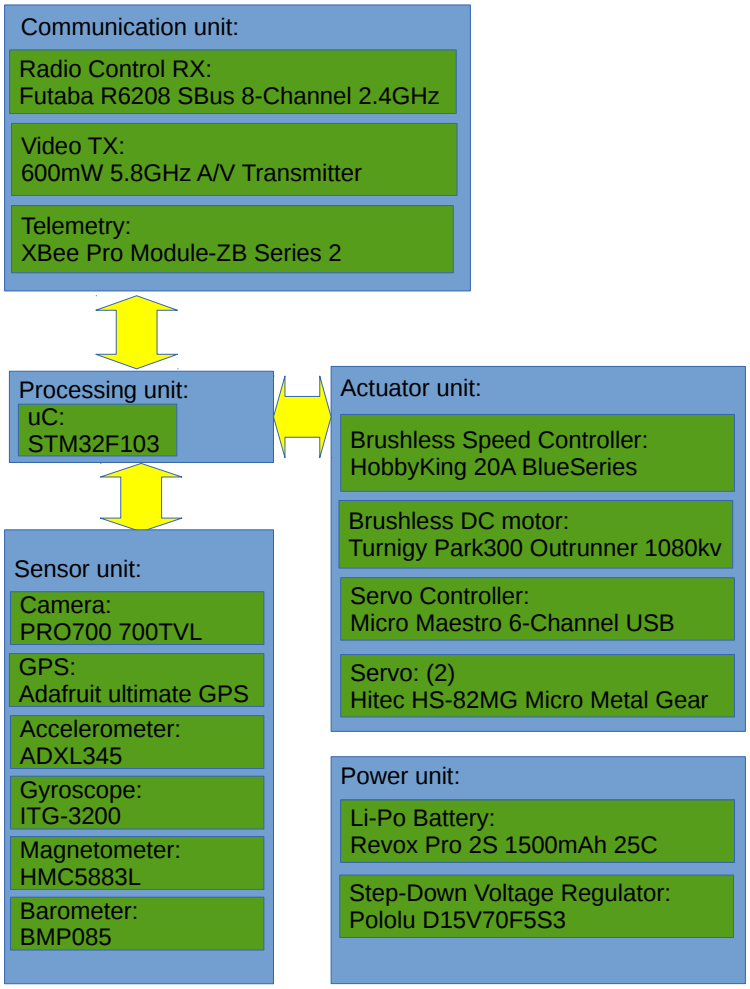

Figure 1: The high level block diagram of the proposed system.

Table 1: The gantt chart

WBS	**Nov**				**Dec**				**Jan**				**Feb**				**Mar**			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
1a: ee design	X	X	X																	
1b: ee purchasing			X	X	X															
1c: ee comm					X															
1d: ee sensor					X															
1e: ee actuator						X														
1f: ee power						X														
1(g)i: ee intgr							X	X												
1(g)ii: ee-me intgr								X	X	X										
2a: ctrl design			X	X	X	X	X	X	X	X										
2b: ctrl impl										X	X	X	X	X						
2c: ctrl test														X	X	X	X	X	X	
3b: reports																			X	X
3a: demo																		X		X

2.3 Milestones

1. *Milestone-1 (Dec: Week-3)* ee-only integration
2. *Milestone-2 (Jan: Week-3)* ee-me integration
3. *Milestone-3 (Feb: Week-3)* first trial
4. *Milestone-4 (Mar: Week-2)* first demo
5. *Milestone-5 (Dec: Week-4)* hand-off

3 Hardware

This section lists all hardware that is *on-board* on the robot body. For procurement information, refer to section 6. For the summary of dimensions and weights, refer to table 2.

3.1 Processing units

We employ a BeagleBone Black as the main processing unit. It uses an AM335x 1GHz ARM Cortex-A8 processor. Its key specifications are as follows:

- 512MB DDR3 RAM
- 2GB 8-bit eMMC on-board flash storage
- 3D graphics accelerator
- NEON floating-point accelerator
- 2x PRU 32-bit microcontrollers
- compatible with Ångstrom, Android, Ubuntu
- USB client for power and communications
- USB host, Ethernet, HDMI, 2 x 46 pin headers
- dimensions: 86.36mm x 53.34mm x 4.76mm
- weight: 39.68 grams

As an alternative (and probably a complement), we use one Flymaple, which is a Quadcopter controller board based on the Maple Project. Its specifications include:

- Microcontroller: STM32F103
- Running at 72Mhz with 32bit Arduino sytle ARM processor(Cortex-M3)
- ITG-3200 - triple-axis digital-output gyroscope
- ADXL345 - 13-bit resolution, 16g, triple-axis accelerometer
- HMC5883L - triple-axis, digital magnetometer
- BMP085 - high-precision barometric pressure sensor
- Programable through an Arduino-based development environment - Maple IDE
- Extends 6 channels PWM pins for controlling ESC/Servo
- Extends 8 channels GPIO for capturing RC receiver output
- Serial port 1
- GPS extension port
- I2C interface
- Size: 50x50x12mm
- Weight: 15g

3.2 Communication units

3.2.1 Data communication

This communication channel is mainly used for data (images, measurement results) acquisition to the ground, not for flight control signals. For the latter, refer to subsubsection 3.2.2.

The wireless communication for measurement (sensing) data is based on Zigbee protocol. In particular, we use an XBee Pro Module ZB Series 2. Its technical details are as follows:

- TX Peak Current: 205mA
- RX Current: 47 mA (@3.3 V)
- power-down Current: $< 3.5\mu A$
- indoor/Urban: up to 300 ft (90 m)
- outdoor line-of-sight: up to 2 miles (3200 m)
- transmit Power: 63mW (18dBm)
- receiver Sensitivity: -102 dBm
- dimensions: 24mm x 33mm x 9mm
- weight: 3.91 grams

A USB XBee Adapter provides a cost-effective solution to interfacing the main processing unit to the XBee Pro module. Its key specifications are as follows:

- Provides an easy interface to configure XBee Modules using Digi's X-CTU software
- 4 status indicator LEDs for Power, RSSI, Associate and mode (sleep/ON)
- Power requirements: 5.0V from USB or VDD pin, 3.3V generated on-board
- Communication: Serial pass-through to XBee module/USB to Host PC
- Operating temp range: -40 to +158F (-40 to +70C)
- Dimensions: 38.3 x 25.6 x 14.8 mm
- Weight: 4g

As an alternative, we may also use an XBee 5V/3.3V Adapter Board.

In addition, to accomodate visual data, we utilize a Revox Pro 5.8GHz 400mW AV Tx-Rx Set with an ImmersionRC 5.8GHz Circular Polarized spiroNet Antenna. Its specifications are as follows.

- Transmitter frequency: 5645-5945MHz;8CH
- Transmitting Power: 400mW/25dBm
- Transmitting distance: $> 1000m$ (open area)
- Frequency control: built-in frequency and phase lock loop
- AV input:analog AV signal input
- ANT connector: SMA (inside the needle)
- Power supply: 6.5-12volts
- Current supply: 300mA
- Size: 55 x 26 x 17mm
- Net weight: 43g

Table 2: Hardware dimensions (milimeters) and weights (grams)

Type	Dimensions	Weight
BeagleBone Black and or FlyMaple	86.36 x 53.34 x 4.76	39.68
XBee Pro Module - ZB Series 2	24.00 x 33.00 x 9.00	3.91
USB XBee Adapter	38.30 x 25.60 x 14.80	4.00
FrSky DF 2.4Ghz Receiver	55 x 25 x 14	12.4
Revox Pro 5.8GHz 400mW AV Tx	55.00 x 26.00 x 17.00	52.00
MinIMU-9 v2	20.00 x 13.00 x 3.00	0.70
Turnigy Micro FPV Camera	34.00 x 34.00 x 30.00	40.00
Adafruit v3 GPS	25.50 x 35.00 x 6.50	8.50
Turnigy Park300 BLDCM	27.00 x 23.00	25.00
Hitec HS-82MG Micro Servo	30 x 30 x 12	19.00
20A BlueSeries ESC	33 x 23 x 6	18.00
Micro Maestro Servo Controller	21.59 x 30.48 x 6.00	4.80
7.4V 2200mAh Turnigy Lipo Battery	12 x 35 x 18	133.00
D15V70F5S3 Step-Down VR	48.00 x 15.00 x 8.00	6.00
ACS715 Current Sensor	17.78 x 20.32	1.30
Cables and connectors	n.a	1.00
TOTAL	n.a	369.29

- Gross weight: 52g

Whereas, the antenna specifications includes:

- Clover (TX) weight: 7.7g
- Skew (RX) Weight: 8.6g
- Connector: SMA (Fatshark/ImmersionRC compatible)
- Case size: 33.5m(w) 16mm(h)
- Cable Length: 73mm(skew) 33.5mm(clover)

3.2.2 Control communication

For receiving control signals for teleoperation, we use a FrSky DF 2.4Ghz Combo Pack for JR with Module and RX. This is coupled with the transmitter explained in subsection 5.4. Its specifications are as follows. Receiver specifications include:

- Operating voltage: 3.5 - 10.0V
- Power consumption: 100mA
- Resolution: 3072
- Latency: 22ms
- Analog voltage: 0 to 3.3V
- Number of channels: 8
- Range: 1.5km-2.5km
- Dimensions: 55 x 25 x 14 mm
- Weight: 12.4g

Module specifications include:

- Operating voltage: 6.0V-13.0V (can handle 3S!)
- Power consumption: 50mA
- Output Power:: 60mW
- Resolution: 3072 (11bit)
- Dimensions: 63.9x48.5x36.5mm

3.3 Sensor units

3.3.1 IMU

We utilize an Pololu MinIMU-9 v2. It is an inertial measurement unit (IMU) that packs an L3GD20 3-axis gyro and an LSM303DLHC 3-axis accelerometer and 3-axis magnetometer onto a tiny board. Its specifications are as follows:

- Operating voltage: 2.5 to 5.5 V
- Supply current: 10 mA
- Output format (I2C): Gyro: one 16-bit reading per axis; Accelerometer: one 12-bit reading (left-justified) per axis; Magnetometer: one 12-bit reading (right-justified) per axis
- Sensitivity range (configurable): Gyro: ±250, ±500, or ±2000 deg/s; Accelerometer: ±, ±4, ±8, or ±16 g; Magnetometer: ±1.3, ±1.9, ±2.5, ±4.0, ±4.7, ±5.6, or ±8.1 gauss
- Dimensions: 20 x 13 x 3 mm
- Weight without header pins: 0.7 g

3.3.2 Cameras

We employ a Turnigy Micro FPV Camera with the following specifications:

- Camera Type: Colour NTSC
- Pick Up Device: 1/3" Sony EXview 960H CCD
- Pic Elements: 976(H) x 494(V)
- Resolution: 700TV Lines
- Min Illumination: 0.01 Lux / F2.0
- Lens: 2.1mm wide angle as standard
- Voltage: DC5v to 15V

- Power: 55mA to 150mA
- Dimensions: 34 x 34mm
- Weight: 40g (minus cables)

3.3.3 GPS modules

We use an Adafruit Ultimate GPS Breakout - 66 channel w/10 Hz updates - Version 3. Its key specifications are as follows.

- Satellites: 22 tracking, 66 searching
- Patch Antenna Size: 15mm x 15mm x 4mm
- Update rate: 1 to 10 Hz
- Position Accuracy: 1.8 meters
- Velocity Accuracy: 0.1 meters/s
- Warm/cold start: 34 seconds
- Acquisition sensitivity: -145 dBm
- Tracking sensitivity: -165 dBm
- Maximum Altitude for PA6H: according to the factory, this module will perform up to 40Km but it is only known-tested up to 27,000 Meters
- Maximum Velocity: 515m/s
- Vin range: 3.0-5.5VDC
- MTK3339 Operating current: 25mA tracking, 20 mA current draw during navigation
- Output: NMEA 0183, 9600 baud default
- DGPS/WAAS/EGNOS supported
- FCC E911 compliance and AGPS support (Offline mode : EPO valid up to 14 days)
- Up to 210 PRN channels
- Jammer detection and reduction
- Multi-path detection and compensation
- Dimensions (not including coin cell or holder): 25.5mm x 35mm x 6.5mm
- Weight (not including coin cell or holder): 8.5 gram

3.4 Actuator units

3.4.1 DC motors

We use one Turnigy Park300 Brushless Outrunner 1080kv motor for the flapping mechanism. It is a brushless outrunner with the following specifications:

- Battery: 2 to 3 Cell /7.4 to 11.1V
- RPM: 1080kv
- Max current: 9A
- No load current: 11V/0.2A
- Internal resistance: 0.04 ohm
- Diameter of shaft: 3mm
- Dimensions: 27x23mm
- Weight: 25g (not including connectors)

3.4.2 Servo motors

We use one Hitec HS-82MG Micro Metal Gear servo with the following specifications:

- Motor Type: 3 Pole
- Bearing Type: Top Ball Bearing
- Speed at 4.8v: 0.12 sec at 60 deg.
- Speed at 6v: 0.10 sec at 60 deg.
- Torque at 4.8v: 2.8 kg.cm
- Torque at 6v: 3.4 kg.cm
- Size: 30 x 30 x 12mm
- Weight: 19g

3.4.3 Motor controllers

We use one HobbyKing 20A BlueSeries Brushless Speed Controller. It is built with imported N-Channel mosFET's and an ultra fast Atmel MCU and heartbeat make this a high performance ESC with excellent sync capabilities. Its specifications are as follows:

- Cont. Current: 20A
- Burst Current: 30A
- Battery: 2-4 Cell Lipo / 5-12 Cell Ni-XX
- SBEC: 5V/ 2A Output
- Size: 33 x 23 x 6mm Weight: 18g

To accomodate speed and position control, we utilize several A3144 hall-effect sensor. Its specifications/features are as follows:

- 4.5 V to 24 V Operation, Needs Only An Unregulated Supply
- Open-Collector 25 mA Output, Compatible with Digital Logic
- Reverse Battery Protection
- Activate with Small, Commercially Available Permanent Magnets
- Solid-State Reliability

3.4.4 Servo controllers

We use a Micro Maestro 6-Channel USB Servo Controller with the following features:

- Three control methods: USB, TTL (5V) serial, and internal scripting
- $0.25\mu s$ output pulse width resolution (corresponds to approximately 0.025 for a typical servo, which is beyond what the servo could resolve)
- Pulse rate configurable from 33 to 100 Hz
- Wide pulse range of 64 to 3280 s (2)
- Individual speed and acceleration control for each channel
- Channels can be optionally configured to go to a specified position or turn off on startup or error

Table 3: Power consumption in Watts

Type	P
BeagleBone Black	1.0
XBee Pro Module - ZB Series 2	1.0
USB XBee Adapter	1.0
FrSky DF 2.4Ghz Receiver	1.0
Revox 5.8GHz AV Tx-Rx	2.1
MinIMU-9 v2	0.1
Turnigy Micro FPV Camera	1.0
Adafruit v3 GPS	0.1
Turnigy Park300 BLDCM	18.0
HSG-8315BH servo	2.0
20A BlueSeries ESC	0.1
Micro Maestro Servo Controller	0.1
Step-Down Voltage Regulator	0.2
ACS715 Current Sensor	0.1
TOTAL	27.8

- Channels can also be used as general-purpose digital outputs or analog inputs
- Dimensions: 21.59 x 30.48 x 6.00
- Weight of 4.8 g with headers

3.5 Power units

3.5.1 Batteries

Given the aforementioned hardware, the summary of power consumption is provided in table 3. Notice that the data are merely approximations.

We use one Turnigy nano-tech 2200mAh 2S (25 to 50C) Lipo Pack with the following specifications:

- Capacity: 2200mAh
- Voltage: 2S1P / 2 Cell / 7.4V
- Discharge: 25C Constant / 50C Burst
- Dimensions: 112x35x18mm
- Weight: 133g (including wire, plug and case)

Thus, it approximately contains 16.28 Wh energy; assuming a constant voltage. Given the fact that our electrical power consumption is of 27.8 W, this battery will last in approximately 35.14 minutes.

3.5.2 Voltage regulators

We use a Pololu Step-Down Voltage Regulator D15V70F5S3 with the following specifications:

- input voltage: 4.5 V to 24 V
- typical continuous output current: 7 A (Actual continuous output current depends on thermal dissipation. See Output Current section below for details)
- output voltage selectable as 5 V or 3.3 V
- 700 kHz switching frequency
- 45 mA typical no-load quiescent current (300 μA typical quiescent current with ENABLE=0V)
- integrated over-temperature and over-current shutoff
- dimensions:48mm x 15mm x 8mm
- weight without header pins: 6 grams

3.5.3 Current monitoring

We use one ACS715 Current Sensor for current monitoring, i.e. to trigger landing procedures whenever the power is low. Its specifications include:

- Current sense: 0.133 V/A1
- Minimum logic voltage: 4.5 V
- Maximum logic voltage: 5.5 V
- Supply current: 13 mA
- Size: 17.78mm x 20.32
- Weight: 1.3 g

3.6 Ancillary

Several types of cables and connectors are required; at this point, they have not been precisely identified. Anything needed for wiring and connections should also be mentioned here. We may need a USB hub.

4 Software

We are committed to open-source and free software. Therefore, proprietary software use should be minimized.

4.1 Operating systems

On the main processing unit, we run the Ångstrom Linux distribution. It is a stripped down version of Linux specifically designed for embedded devices.

4.2 Languages and compilers

We mainly use C/C++ and Python v2.x, with the gcc v4.x compiler and the CMake build manager for the former. Notice that I2C is only compatible with Python2 due to the python-smbus dependency.

The C/C++ and Ptyhon codes *must* adhere the Google C++ Style Guide[1] and the Google Python Style Guide[2], respectively.

[1] http://google-styleguide.googlecode.com/svn/trunk/cppguide.xml
[2] http://google-styleguide.googlecode.com/svn/trunk/pyguide.html

4.3 Code management

We rely on Git (git-scm.com) for revision control and source code management. For source code hosting, we may consider the GitHub. We also used the doxygen for neat and effective documentation.

4.4 Libraries

We utilized some reliable libraries such as:

- OpenCV: for computer vision
- Boost
- Eigen, Numpy: for numerical computations
- scikit-learn, PyBrain: for machine learning
- RL-Glue: for reinforcement learning

4.5 Control algorithm

Purportedly, we leverage reinforcement learning to make the robot fly.

5 Tools

This section contains devices that are used during the development process including debugging and testing. In addition, hardware for controlling the robot teleoperatedly is explained here. For procurement information, refer to section 6.

5.1 Development units

These include a workstation along with a keyboard, a mouse and a monitor with HDMI-input. Furthermore, internet connection and LAN infrastructure must be provided.

5.2 XStick ZB USB Adapters

We require a USB to XBee wireless adapter, namely a XStick ZB USB dongle that is plugged in to the workstation. It specifications include:

- USB plug-and-play USB to XBee Network Adapter
- Available in ZigBee mesh (ZB) and multipoint (802.15.4) variants
- Configure and commission XBee networks easily from your laptop or PC

5.3 Battery chargers

We rely on an IMAX B6-AC Charger/Discharger 1-6 Cells with the following specifications:

- Input Voltage: 11 to 18v
- Circuit power: Max Charge: 50W / Max Discharge: 5W
- Charge Current Range: .1 5.0A
- Discharge current range: .1 1.0A
- Ni-MH/NiCd cells: 1 15
- Li-ion/Poly cells: 1 6
- Pb battery voltage: 2 20v
- Weight: 580g
- Dimensions: 133x87x33mm

5.4 Ground controllers

To accomodate convenient and intuitive teleoperations, we require a device in the form of RC remote controllers or playstation joysticks. In particular, we use a Turnigy 9XR with the following specifications:

- Channnel: 8ch ppm/9ch pcm
- Display: 128 x 64LCD (Backlit)
- Support Type: Heli/Acro/Glid
- Model Memory: 16
- Stick modes: 1, 2, 3, 4
- Encoder type: ppm/pcm
- Module Interface: JR Compatible (See Related Items Below)
- Simulator Interface: Yes (JR and Futaba)
- Buzzer: Yes
- Battery Compartment: 112 x 44 x 27mm
- Weight (less battery and Rf Module): 723g

5.5 Brushed DC motor controllers

To accomodate integration tests, we need to control several brush DC motor. Therefore, we require several Pololu Jrk 21v3 USB Brushed DC Motor Controllers.

6 Procurement

This section summarizes the procurement of hardware and software, including what and where to buy and how much? The information is listed in table 4 and 5.

Notice that most data are time-variant and the shipping costs are excluded. The quantity of items is the minimum; not considering backups.

7 Revision control

7.1 Revision 0

- Revision 0.0:
  - Initialized and created!
- Revision 0.1:
  - Added noticeable projects in the Intro.
  - Changed the used python version to v.2.x
  - Fixed tool procurement: merging peripherals to workstations

Table 4: Hardware ordering details

Type	Manufacturer	Qty	Unit Price	Distributor
BeagleBone Black	beagleboard.org/	1	USD 45.00	www.adafruit.com/
Flymaple	www.open-drone.org/	1	IDR 699K	www.famosastudio.com/
XBee Pro Module - ZB Series 2	www.digi.com/	1	USD 37.95	www.adafruit.com/
USB XBee Adapter	www.parallax.com/	1	USD 20.00	www.adafruit.com/
RG831B 8ch 2.4GHz Receiver	www.jrpropo.co.jp/	1	USD ?	?
Revox Pro 5.8GHz AV Tx-Rx	?	1	IDR 1703K	www.aeroflyhobbies.com/
5.8GHz Circ. Pol. Antenna	www.immersionrc.com/	1	USD 34.89	hobbyking.com/
MinIMU-9 v2	www.pololu.com/	1	USD 39.95	www.pololu.com/
Turnigy Micro FPV Camera	www.turnigy.com/	1	USD 149.99	www.hobbyking.com/
Adafruit v3 GPS	www.adafruit.com/	1	USD 39.95	www.adafruit.com/
Turnigy Park300 BLDCM	www.turnigy.com/	1	USD 13.99	www.hobbyking.com/
Hitec HS-82MG Micro Servo	www.hitecrcd.com/	1	USD 19.32	www.hobbyking.com/
20A BlueSeries ESC	www.hobbyking.com/	1	USD 10.78	www.hobbyking.com/
Micro Maestro Servo Controller	www.pololu.com/	1	USD 19.95	www.pololu.com/
7.4V 2.2Ah Lipo Battery	www.turnigy.com/	1	USD 11.84	hobbyking.com/
D15V70F5S3 Step-Down VR	www.pololu.com/	1	USD 24.95	www.pololu.com/
ACS715 Current Sensor	www.pololu.com/	1	USD 9.95	www.pololu.com/
Cables and connectors	any	1	USD ?	any

Table 5: Tool ordering details

Type	Manufacturer	Qty	Unit Price	Distributor
Workstation	any	1	IDR ???K	any
LAN infrastructure	any	1	???	any
internet connection	any	1	???	any
XStick ZB USB Adapters	www.digi.com/	1	USD 49.00	store.digi.com/
IMAX B6-AC battery charger	www.imaxrc.com/	1	USD 39.99	hobbyking.com/
Turnigy 9XR Transmitter	www.turnigy.com/	1	USD 50.22	www.hobbyking.com/
FrSky DF 2.4Ghz Combo Pack	www.frsky-rc.com/	1	USD 52.93	www.hobbyking.com/
Pololu Jrk BDCM Controllers	www.pololu.com/	2	USD 51.95	www.pololu.com/

- Revision 0.2:
  - Added the sensor: GPS
  - Added some potential libraries to utilize
  - Initiated higher level software subsec.

7.2 Revision 1

- Revision 1.0:
  - Changed the doc. title
  - Added RC system for teleoperation
  - Specified GPS modules further
  - Updated the hi-level block diagram
  - Initiated the schedule sec.
  - Refined the power unit sec.
  - Changed accelerometer to IMU
  - Changed battery spec.
- Revision 1.1:
  - Updated the management sec.
  - Refined comm. unit sec.
  - Added the FlyMaple and camera spec.
  - Updated HW related tables
- Revision 1.2:
  - Updated noticeble products: Avitron2.0
  - Added current sensors
  - Updated DC motors, motor controllers
  - Updated servo motors
  - Added coding styles, doxygen
  - Added milestones