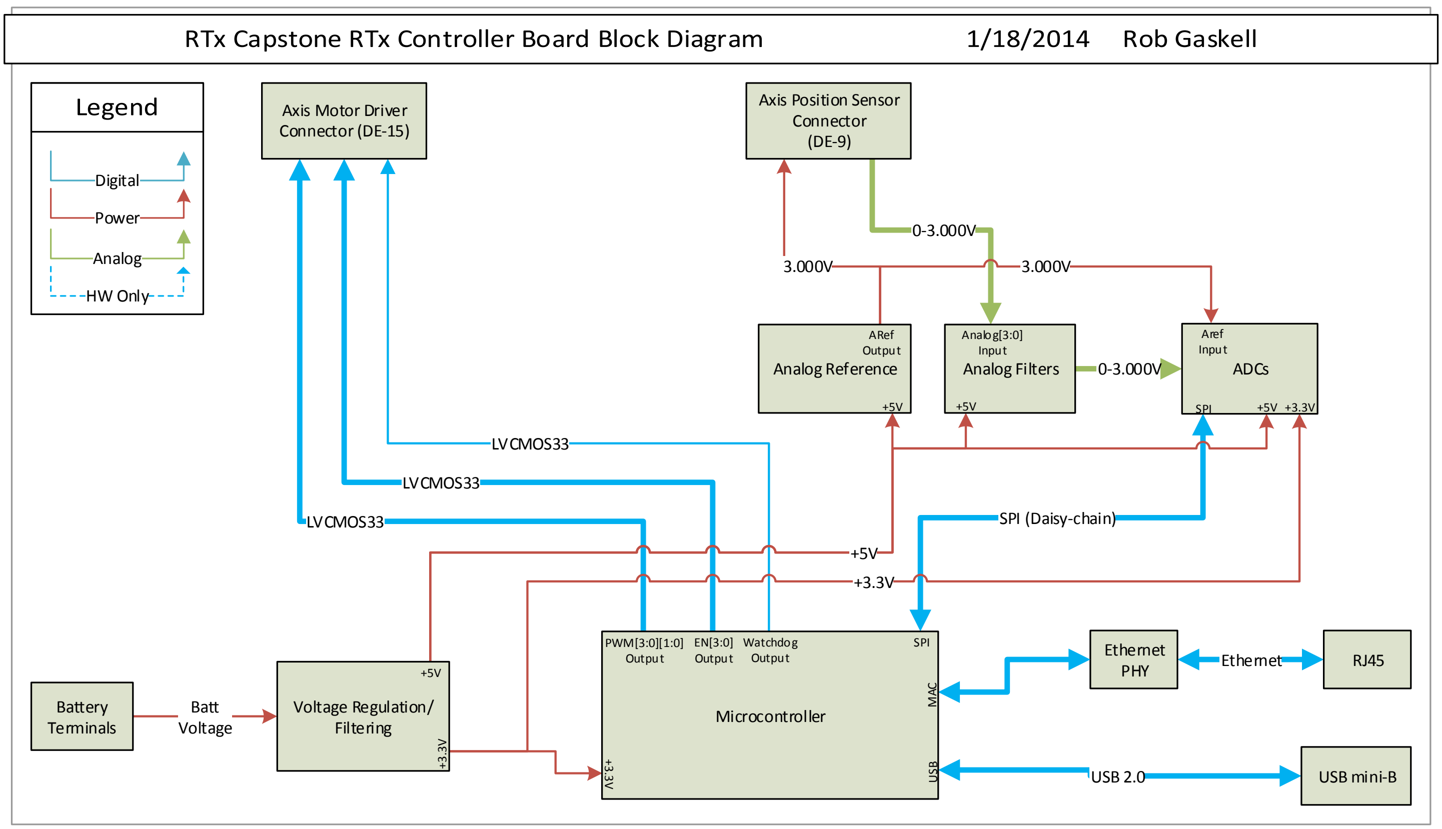
RTx Controller Board Design Document

RocketTracks Capstone 2014

The RocketTracks Controller board controls the position of the axes on the RocketTracks camera and antenna pointer. The RTx Controller Board features an Ethernet port for communication with input control devices, as well as a USB port to aid in firmware development and debugging. Commands and tracking data will be sent via Ethernet to the RTx Controller board, and the onboard microcontroller will process the data and output PWM and other control signals to the Generic Motor Driver boards for each axis.



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A. Axis Position Feedback Overview

RocketTracks uses a potentiometer as a position sensor for each axis. The output voltage is filtered and compared to the input reference voltage via an on-board ADC. The Low-Pass Filter is designed based on control theory requirements, and is a compromise of noise-reduction and phase margin requirements.

B. Analog-to-Digital Converters (ADC's) for Feedback circuits

1. Component List

a) ADC1

C1	C4	C5	ADC1

b) ADC2

C2	C6	C7	ADC2

c) ADC3

C3	C8	C9	R16	ADC3

d) ADC4

C40	C41	C42	R20	ADC4

e) Analog Reference Voltage Regulator

C23	C24	C25	REF1

2. Design Overview

a) ADC Resolution

The resolution of the axis position feedback ADC's corresponds to the resolution of measurement of the angular position of the axis. Assuming the potentiometer provides a resistance through the axis range of motion which is linear with angle and corresponds to a full-range output voltage sweep through a 360-degree rotation, we have:

$$Resolution_{\theta} = \frac{360^{o}}{2^{Resolution_{ADC}}} \Rightarrow Resolution_{ADC} = \log_2 \frac{2\pi\, rad}{Resolution_{\theta}}$$

The tracking precision required at full-range is then:

$$Resolution_{Range} = Sin(Resolution_{\theta}) * Range$$

$$\Rightarrow Resolution_{\theta} = \arcsin\left(\frac{Resolution_{Range}}{Range}\right)$$

$$\Rightarrow Resolution_{ADC} = \log_2 \frac{2\pi\, rad}{\arcsin\left(\frac{Resolution_{Range}}{Range}\right)}$$

We must track a ~2m length object at distances in excess of 18,000ft. However, we need not stay perfectly centered on the rocket at this distance, as video will not be at full zoom, and telemetry signals require less precision than video. Assuming we want to keep the rocket both in the frame and zoom such that the rocket length is 5% of the frame, the tracking resolution at this range becomes:

$$Resolution_{Range} = \frac{2m}{10\%} = 20m$$

$$Resolution_{ADC} = \log_2\left(\frac{2\pi\, rad}{\arcsin\left(\frac{20m}{5500m}\right)}\right) = 11bits$$

However, the control system will not be capable of tracking to 1 LSb of the ADC, so as a rule of thumb we will assume tracking precision to within 30% of ADC resolution. Then we have:

$$Resolution_{ADC} = 11bits + 30\% * 11bits = 15\ bits$$

As ADC's are most commonly available in power-of-2 resolutions, a 16 bit ADC will be used.

b) ADC Digital Interface

Given a sample rate of 2000Hz as described in section B.3.a below, we must have a data bandwidth of 2kSamples/sec, with a sample size of 16 bits or 2 Bytes. We must then have a data bandwidth of 4kB/s for each ADC, or 16kB/s if they are on a shared or daisy-chained bus. However, latency is of great concern in a control system, so it is not sufficient that the data transfer complete within the sample period.

A daisy-chain SPI interface allows a single sample command to be issued to all ADC's simultaneously, and allows a single data transfer from all axes to be performed with lower overhead as compared to a chip-select based SPI interface.

c) ADC and Analog Reference Voltage Regulator Choice

Common ADC data buses are I2C and SPI. The AD7685 is a 16-bit ADC supporting both SPI and daisy-chain serial interfaces at up to 55MHz, or more than 6.5MB/s. It also has a sample rate of up to 250kSamples/s, and a sample-to-data ready time of no more than 2.2us, minimizing latency and satisfying throughput requirements.

(1) ADC Supply Voltages

The AD7685 has separate supplies for the converter and for the digital I/O interface. V_{IO} was chosen to match that of the microcontroller, while V_{DD} selection was based on the desire to minimize conversion latency, as higher voltages allow for faster conversion times as well as higher conversion rates. The following voltages were chosen:

$$V_{IO} = 3.3V$$

$$V_{DD} = 5V$$

(2) Reference Voltage Regulator Choice

A stable and noise-free reference voltage is required for the ADC and feedback position sensor potentiometer circuits. The chosen analog reference voltage regulator is recommended for use with the AD7685, and is offered in a range from $2.048V\ to\ 5.000V$. The $5.000V$ model, ADR435, was chosen as the higher voltage maximizes the signal-to-noise ratio.

(3) ADC Decoupling Capacitors

Per the datasheet, 0.1uF capacitors were chosen to decouple the supply pins. A 1206-package 22uF capacitor with an X5R temperature coefficient decouples the analog reference input pin, as this is the recommended value when using an ADR43x reference voltage regulator.

(4) Analog Reference Supply Decoupling Capacitors

The ARef regulator's supply pin is decoupled with a 10uF and 0.1uF capacitor, and the output is decoupled with a 0.1uF capacitor, per the device datasheet.

3. Summary of Parameters

$Resolution_{5500m} = 20m$

$Resolution_{ADC} = 16\ bits$

$V_{aref} = 5.000V$

$V_{DD,ADC} = 5V$

$V_{DD,aref} = ?\,V$

$V_{IO,ADC} = 3.3V$

C. Low-Pass Filters for Feedback ADC's

1. Component List

a) ADC1 Feedback LPF

R1	R2	R3	C10	C11	C12	C13	OPAMP1-A

b) ADC2 Feedback LPF

R4	R5	R6	C14	C15	C16	C17	OPAMP1-B

c) ADC3 Feedback LPF

R7	R8	R9	C18	C19	C20	C21	OPAMP2-A

d) ADC4 Feedback LPF

R17	R18	R19	C36	C37	C38	C39	OPAMP2-B

2. Design Overview/Component Choice

a) Control Bandwidth and Cutoff Frequency

The control bandwidth frequency f_{CBW} for the closed-loop control system was chosen based on the requirement to track fast-moving objects with video during manual and automated control operation. The cutoff frequency f_C for the ADC input LPF is specified to be one decade higher than f_{CBW}. This convention places f_C far enough above the f_{CBW} to prevent the LPF from limiting performance at the f_{CBW}, while still providing satisfactory noise filtering.

$$f_{CBW} = 2.5Hz$$

$$f_C = 2.5Hz * 10 = 25Hz$$

b) ADC 1-bit Frequency, desired noise level and Filter Order

The frequency of the ADC's LSB f_{1bit} is the minimum frequency at which we will observe a change on the least significant bit. The maximum noise level desired at f_{1bit} is -96dβ. f_{1bit} must be a low enough frequency such that the Nyquist rate is reasonable given our choice of ADC's and microcontroller. With a 3rd Order LPF with our $f_C = 25Hz$, we have:

$$f_{-96d\beta} = 995Hz$$

The Nyquist rate, or minimum rate we must sample the ADC's is then $995Hz * 2 = 1090Hz$, which is a reasonable sample rate for the system.

c) Topology

A Sallen-Key topology Butterworth Low-Pass Filter was chosen due to its simplicity, and the ability to attain 3rd-order filtering and a low f_C with relatively low RLC values in combination.

d) Op-Amp

The AD861x Op-Amp was chosen to produce the Sallen-Key topology because it is recommended for use in conjunction with the chosen ADC's.

3. Consequences

a) Control Rate and ADC Sampling

A rule of thumb for minimum control rate is $f_{CR} \geq f_{CBW} * 40$, then:

$$f_{CR} \geq 2.5Hz * 40 \geq 100Hz$$

The Nyquist rate must also be satisfied, so the sample rate must be:

$$f_S \geq 1080Hz$$

Choosing $f_{CR} = 100Hz$ and $f_S = 2000Hz$ gives us 20 samples per control loop iteration.

4. Summary of Parameters

$f_{CBW} = 2.5Hz$

$f_C = 25Hz$

$f_S = 2000Hz$

$f_{CR} = 100Hz$

II. Microcontroller

III. Ethernet Port

IV. USB Development/Debug Port

V. Supply Voltage Regulation/Filtering

VI. Motor Driver Outputs