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.



# Table of Contents

[Axis Position Feedback 3](#_Toc379637398)

[Axis Position Feedback Overview 3](#_Toc379637399)

[Analog-to-Digital Converters (ADC’s) for Feedback circuits 3](#_Toc379637400)

[Component List 3](#_Toc379637401)

[Design Overview 3](#_Toc379637402)

[Summary of Parameters 5](#_Toc379637403)

[Low-Pass Filters for Feedback ADC’s 5](#_Toc379637404)

[Component List 6](#_Toc379637405)

[Design Overview/Component Choice 6](#_Toc379637406)

[Consequences 7](#_Toc379637407)

[Summary of Parameters 7](#_Toc379637408)

[Microcontroller 7](#_Toc379637409)

[Ethernet Port 7](#_Toc379637410)

[USB Development/Debug Port 7](#_Toc379637411)

[Supply Voltage Regulation/Filtering 7](#_Toc379637412)

[Motor Driver Outputs 7](#_Toc379637413)

# Axis Position Feedback

## 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.

## Analog-to-Digital Converters (ADC’s) for Feedback circuits

### Component List

#### ADC1

|  |  |  |  |
| --- | --- | --- | --- |
| C1 | C4 | C5 | ADC1 |

#### ADC2

|  |  |  |  |
| --- | --- | --- | --- |
| C2 | C6 | C7 | ADC2 |

#### ADC3

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| C3 | C8 | C9 | R16 | ADC3 |

#### ADC4

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| C40 | C41 | C42 | R20 | ADC4 |

#### Analog Reference Voltage Regulator

|  |  |  |  |
| --- | --- | --- | --- |
| C23 | C24 | C25 | REF1 |

### Design Overview

#### 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:

The tracking precision required at full-range is then:

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:

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:

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

#### 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.

#### 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.

##### ADC Supply Voltages

The AD7685 has separate supplies for the converter and for the digital I/O interface. was chosen to match that of the microcontroller, while 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:

##### 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   
 The model, ADR435, was chosen as the higher voltage maximizes the signal-to-noise ratio.

##### 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.

##### 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.

### Summary of Parameters

## Low-Pass Filters for Feedback ADC’s

### Component List

#### ADC1 Feedback LPF

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| R1 | R2 | R3 | C10 | C11 | C12 | C13 | OPAMP1-A |

#### ADC2 Feedback LPF

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| R4 | R5 | R6 | C14 | C15 | C16 | C17 | OPAMP1-B |

#### ADC3 Feedback LPF

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| R7 | R8 | R9 | C18 | C19 | C20 | C21 | OPAMP2-A |

#### ADC4 Feedback LPF

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| R17 | R18 | R19 | C36 | C37 | C38 | C39 | OPAMP2-B |

### Design Overview/Component Choice

#### Control Bandwidth and Cutoff Frequency

The control bandwidth frequency 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 for the ADC input LPF is specified to be one decade higher than . This convention places far enough above the to prevent the LPF from limiting performance at the , while still providing satisfactory noise filtering.

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

The frequency of the ADC’s LSB is the minimum frequency at which we will observe a change on the least significant bit. The maximum noise level desired at is -96dβ. 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 , we have:

The Nyquist rate, or minimum rate we must sample the ADC’s is then , which is a reasonable sample rate for the system.

#### 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 with relatively low RLC values in combination.

#### 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.

### Consequences

#### Control Rate and ADC Sampling

A rule of thumb for minimum control rate is , then:

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

Choosing and gives us 20 samples per control loop iteration.

### Summary of Parameters

# Microcontroller

# Ethernet Port

# USB Development/Debug Port

## Component List

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| R21 | R22 | C45 | C46 | U2 | X4 |

## Design Overview/Component Choice

The USB port requires ESD protection. For this TI’s TPD4S012 was chosen because it was a cheap and straightforward solution. A 22Ω current-limiting resistor was placed in series on the D+ and D- line. The two capacitors were placed to reduce noise.

# Supply Voltage Regulation/Filtering

# Motor Driver Outputs