MRO Delay Line

Trolley Electronics Design Description

The Cambridge Delay Line Team

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Objective

To describe the design and implementation of the electronics, including the computer interfacing, of the delay line trolley computer.

Scope

This document forms part of the documentation for the delay line final design review. It describes the trolley electronics, including the interaction between delay line hardware and the trolley computer. For a functional description of the trolley software, please see the document "Trolley Software Functional Description".

1 Introduction

The delay line trolley contains many electronic subsystems. These include two computers and onboard actuators, motors and sensors that all cooperate in order to introduce a carefully controlled delay into the optical path. A block diagram illustrating the various subsystems and their interaction is shown in Figure 1.

The core components are a Central Processing Unit (CPU), a Programmable Multi-Axis Controller (PMAC), two analog input/output boards and a power board. They are connected via a PC104 bus that also allows them to be mechanically stacked together. Overall control of the trolley is imposed by the CPU, which communicates with the other core components via the PC104 bus and with peripherals via serial, ethernet and I^2C lines.

The two analog boards are used for measurement of the catseye drive preamplifier, focus, trolley roll, thermometers, accelerometers, limit switch status, supply voltages and some motor signals. They also output control signals to the preamplifier, secondary mirror tip/tilt and focus.

Control of the steering and drive motors is delegated to the PMAC, which receives feedback from the motor encoders either directly in the case of the steering or via a drive amplifier from the drive motor. The PMAC also accepts inputs from limit switches to restrict drive motor behaviour when necessary.

The catseye drive preamplifier accepts a tracking distance error signal from the metrology system via an analog radio link and converts it into a voice coil drive signal which in turn moves the catseye to minimise the tracking error. A differential position sensor measures the position of the catseye, which is monitored by the CPU via an analog I/O card. If the catseye is not in the middle of its range, the CPU tells the PMAC to vary the drive motor speed such that the catseye moves towards the mid-range setting.

The CPU can adjust the preamp behaviour by setting the values of onboard digital resistors connected to its I^2C bus. It also communicates with the drive motor amplifier via a serial line and with the local network via a wireless ethernet link.

The subsystems are described in more detail in the sections below.

2 The Trolley Computer

The delay line trolley CPU is a single board computer embedded in the electronics bay of the trolley. It performs many tasks:

- Receipt of commands from the workstation and streams of data from the metrology system and shear camera via a wireless ethernet link.

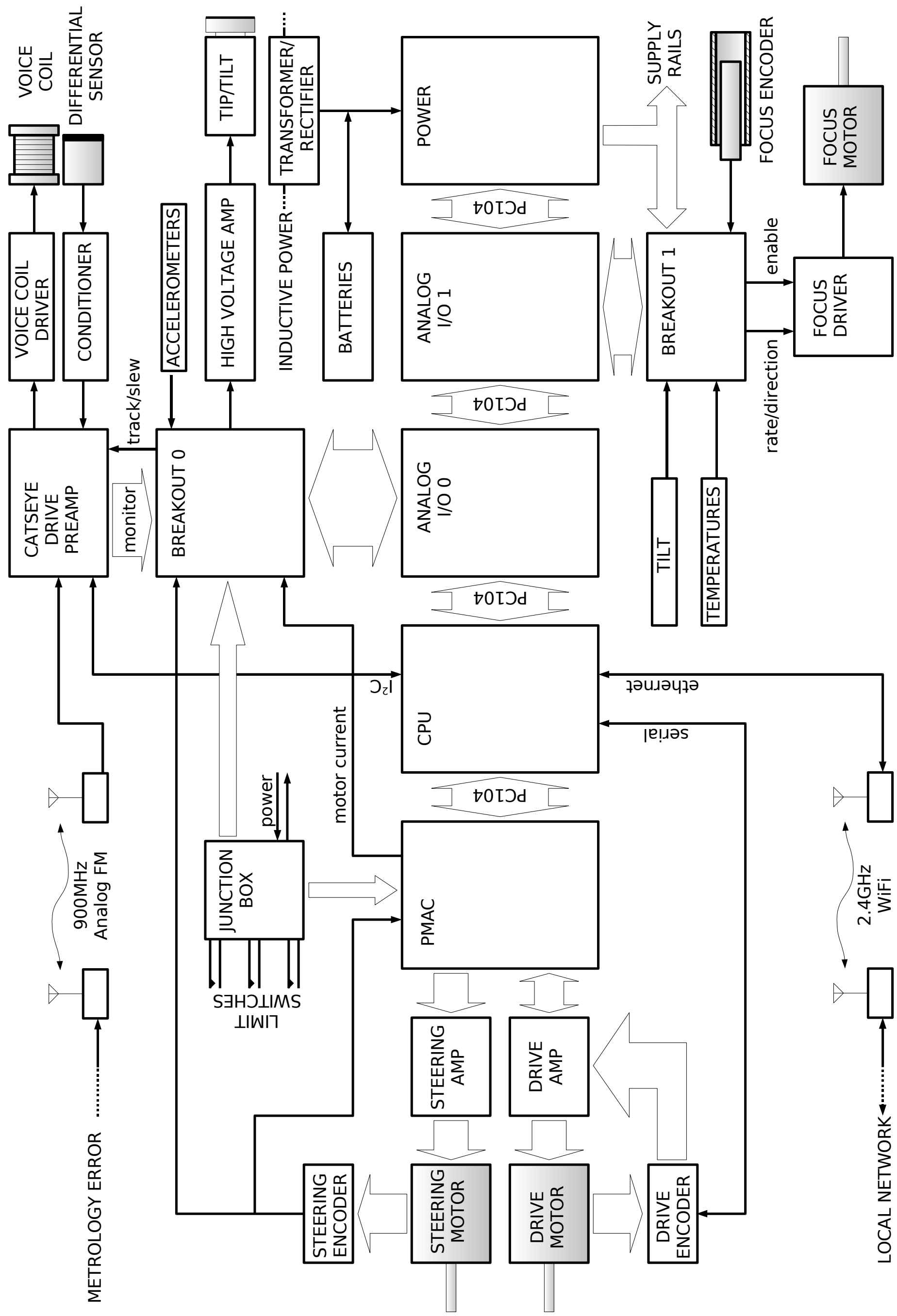

Figure 1: Overview of Trolley Electronics

- Control of actuators and motors on the cart in order to introduce a carefully controlled optical path difference into the delay line.
- Measurement of on-board sensors in order to close servo loops and provide real time feedback and telemetry data for the user.
- Transmission of telemetry data to the workstation for logging and user feedback via the wireless ethernet link.

A variety of interfaces are used. These include a pair of analog input/output boards, a bus interface to a motion controller, serial and ethernet ports, and an I^2C interface.

The computer is an Arcom Viper V1I6 single board computer (this will be a V2I4 in the production cart). It features an Intel PXA255 400MHz ARM compatible processor, five serial ports, an ethernet port and an I^2C interface. The bus is PC104 compatible, allowing the computer and various peripheral boards to be stacked together into a robust, compact unit. The bus is used to communicate with the motor controller and two analog input/output cards, while power is derived from a PC104 compatible switch-mode power supply.

This computer was chosen for its low power consumption, which is vital as there is limited power and heatsinking available. The large number of serial ports was also considered attractive in the early protoyping stages of the design, although most communications functions have since been transferred to the PC104 bus. The availability of a linux development kit also proved useful.

It should be noted that the processor does not contain a floating point unit, hence all floating point calculations are handled in software. While this has been proven to suffice for the prototype trolley, changes made to the floating point load should be tested to ensure there is sufficient processor capacity to handle them.

2.1 Ethernet interface

The trolley computer is equipped with an ethernet interface which is responsible for receipt of commands from the workstation and receipt of remote data from the metrology and shear camera systems (for closure of slow servo loops that span the network). It also transmits its status and diagnostic telemetry information to the workstation for real-time user feedback and diagnostic logging. Finally, an engineer can use the interface to log in remotely to perform tasks beyond the scope of the trolley software.

Trailing cables cannot be used in the delay line so the port is connected to a commercial wireless ethernet transceiver. The other end of this link is an antenna in the end of the delay line pipe connected to a matching transceiver and the local network.

2.2 I^2C interface

The trolley computer's I^2C interface will be used to change the values of digital I^2C potentiometers on the catseye coil drive board, which in turn modify the board's analog servos. Hence these servos can be adjusted while the trolley is otherwise inaccessible within the delay line pipe, and test points described in Table 1 can be used to monitor the effects of these changes. This aspect of the design is not yet implemented on the prototype – the loops are currently tuned using manual trimpots.

It would have been possible to implement the servos in an almost entirely digital fashion, but the analog approach chosen has minimal latency, no digital artefacts and retains some remote adjustment flexibility.

3 The Analog Input/Output Boards

The majority of the interfacing is handled by two Diamond Systems Diamond-MM-48-AT PC104 boards. Each has 16 analog inputs, 8 analog outputs, four digital lines (input or output), 4 optocoupled inputs and 8 relays. They were selected for the wide variety and number of inputs and outputs offered, allowing excellent flexibility during the trolley design phase.

The CPU communicates with the boards by reading from and writing to assigned addresses in the PC104 bus memory space. DMA-style data transfer is not available.

3.1 Analog Inputs

The purpose of the analog input section is to sample on-board sensors and test-point voltages in order to close local servo loops and to transmit information to the workstation for diagnostic logging and real-time user interaction.

Each board has 16 analog inputs, each of which is sampled in turn by a single on-board 16 bit analog to digital converter. Hence the inputs are not sampled simultaneously. The time between adjacent channel samples is configureable and has been set to 5μs. This phase lag between channels is allowed for in the messaging protocol (described in the document "Protocols Document").

Each board has an on-board clock that can be used to run the digitiser. On board 0 this has been set to scan through all 16 channels every 200μs (5kHz), selected as the rate necessary to capture the most rapidly changing signals on the trolley (the accelerometers). The clock signal is available on an output pin and is connected to the external clock input of board 1, which is thereby slaved to sample at the same rate and time as board 0. It is the board 0 clock rather than the CPU clock or an external reference that governs the sample rate and cycle time of the trolley program. This prevents aliasing due to the clocks drifting with respect to each other, and as samples are time stamped by the system clock, time-based comparisons with other data are still possible.

There is a 2048 sample buffer on each board that temporarily stores the digitised data before it is read by the CPU. The buffering is sufficient to allow a program running within a non-real-time operating system to capture all the data.

The buffer provides interrupts to notify the CPU when it is one eighth full and half full. Unfortunately, it was discovered during development that the CPU cannot detect interrupts generated by the board because the board supports shared interrupts while the CPU does not, even though both claim to be PC104 compatible. However, flags indicating the buffer state are also available and as a workaround these are polled every 6.4ms to achieve a similar result.

The allocated inputs and net sample rates as of 28 June 2007 are listed in Table 1. Although all the inputs are sampled at 5kHz, some (such as temperature or supply rail voltage inputs) are not expected to change quickly, and are downsampled in software before conversion into “real” (floating point) quantities to reduce CPU workload and data transmission volume.

3.2 Analog Outputs

Each board is equipped with eight 12-bit digital to analog converters. No buffering or timing is used for these, they simply change value on demand and hold that setting until the next update. Three of the channels are used, all of them to control actuators in the secondary mirror cell. Two are for the orthogonal actuators for the tip-tilt mechanism, which closes the shear servo loop, and the other is a rate signal for the focus actuator, which in conjunction with the focus position value in Table 1 closes the local focus loop.

The converters generate voltages of between 0 and 4.096V, so analog gain and offset stages have been used to make the signals compatible with the tip-tilt stage and the focus mechanism.

3.3 Digital Outputs

There are also four digital channels available on each board, with selectable direction. Two channels are used on the trolley, both as outputs. The first is a signal that sets the mode of the catseye coil preamplifier to either “track” or “slew”: in track mode, the preamplifier tries to keep the catseye at the correct position as specified by the low-latency analog signal from the metrology system, while in slew mode the catseye is locked vertically to prevent damage while the trolley is slewing.

Table 1: COAST Trolley Analog Inputs

Input	Sample Rate (Hz)
Catseye coil drive current	5000
Catseye differential position	5000
Catseye differential velocity	5000
Catseye coil preamp test point 1	5000
Catseye coil preamp test point 2	5000
Motor demand current	100
Motor actual current	100
Axial catseye acceleration	5000
Vertical catseye acceleration	5000
Axial carriage acceleration	5000
Vertical carriage acceleration	5000
Timing sychronisation signal	5000
Roll angle	5000
Secondary mirror focus position	10
Uncommitted temperature sensor	10
Raw transformer voltage	100
+5V supply rail	10
+12V supply rail	10
-12V supply rail	10
Secondary cell temperature	10
Primary cell temperature	10
Front carriage temperature	10
Rear carriage temperature	10
Analog RF signal strength	10
-5V supply rail	10
Energy storage system voltage	10

The second channel enables the focus drive controller. When the controller is disabled its power consumption is reduced. As focusing is rarely necessary, significant power savings can be made by enabling the controller only when it is needed.

The digital channels use 3.3V logic, which is buffered to 5V for compatibility with the focus drive enable input. Any changes to the interfacing should be designed to detect a logic high of 2.4 to 3.3V.

3.4 Other Interfaces

The analog boards are also equipped with optocoupled inputs and relays. Relays are not used in the current design due to the inaccessable and low pressure environment of the delay line: semiconductor alternatives are available that are not susceptible to mechanical failure or low pressure arcing. The optocouplers are not used simply because there has been no need for them.

4 PMAC Motion Controller

Elegant, heart-flutter-inducing poetry to be written here by Martin.

4.1 PC104 Interface

The PMAC motion controller commands the trolley's drive and steering motors by responding to requests from the CPU and through the use of local loops. Communication with the CPU occurs via the PC104 bus using a text based protocol: characters are read from and written to a single address in the CPU's PC104 address space. Effectively the PMAC behaves like a text terminal. Hence transmission of a value across the bus involves sending the text representation of that value rather the binary equivalent.

While this works well for low bandwidth data it consumes valuable bandwidth on the PC104 bus if the data rate is high. Hence high bandwidth data from the PMAC are converted into analog voltages and sent to the analog I/O boards for digitisation and transmission to the CPU. This seemingly retrograde step is more efficient in practice than a direct bus transmission. (XXX is this still true?)

The data written to the PMAC via the PC104 bus are the requested drive motor velocity and steering motor angle. The data received via the PC104 bus are the actual drive motor velocity, an approximate odometer reading, the actual steering angle and various status information. [1] High bandwidth data sent in analog fashion are the drive motor demand and actual currents.

The PC104 version of the PMAC does not use interrupts. Hence, as with the analog I/O cards, it is necessary to poll it to discover if there are characters available to read out. The PMAC is equipped with a 2048 byte buffer which reduces the required polling frequency.

[1] Note that at the time of writing no data is yet received from the PMAC in this way due to its peculiar and undocumented failure to transmit certain control characters. A workaround is under development. The CPU does not use this data, it only forwards it to the workstation for user feedback and logging.

5 Power

Transmission of power to the trolley is via an induction cable that runs the length of the delay line on the bottom inside surface of the pipe. This cable loops through the trolley and forms the primary of an onboard transformer, the secondary of which supplies power that is then rectified and regulated for onboard use. This design avoids cable drag and wear and simplifies cable laying and repair.

5.1 Pickup and Rectification

Wise words by Greybeard here. Ahrrr.

A channel on an analog I/O board is used to monitor the rectified voltage to assist with diagnosing faults.

5.2 Storage

More wise words by Greybeard here. Ahrrr.

5.3 Regulation

A commercial PC104 power board (HE104-HV-16) is used to regulate the raw input power. This is a board designed for automotive use and can handle input voltages up to 48V. The outputs are $\pm$5V and $\pm$12V, which are used to power all trolley devices except the drive amplifier. These voltages are available on screw terminals as well as on the PC104 bus, where they power all devices in the PC104 stack.

6 Shear Control (Secondary Tip/tilt)

The secondary mirror can be tilted in two orthogonal axes by a low voltage piezo-electric actuator. This actuator is used in conjunction with the shear camera to close the shear loop but it can also explicitly be commanded to go to a fixed (usually central) position.

6.1 Signal Conditioning

The two tip-tilt signals are generated by the CPU in response to a pair of shear camera signals that arrive via the wireless ethernet link. The CPU programs two D/A converters on an analog I/O board accordingly, which generate a pair of voltages, each between 0 and 4V. These are then amplified and offset to the range of -10 to 110V that the tip-tilt actuator requires.

Roger Ramjet, anything you want to add here?

6.2 Actuator

The tip-tilt actuator is a commercial Piezosystem Jena PSH-10, which can tilt $\pm$5mrad in two orthogonal axes in response to the pair of input voltages. No strain gauge is present, nor is one necessary, as any piezolelectric hysteresis is automatically compensated for by the shear servo. This also minimises the size, weight and power consumption of the secondary mirror cell and its associated electronics.

7 Focus

The focus mechanism is used to translate the secondary mirror along the cart axis, thereby compensating for expected tolerances in the primary mirror focal length during initial assembly and for thermal variations in the catseye length during a night's observing.

The mechanism consists of a New Focus picomotor to move the secondary mirror and a Linear Variable Differential Transformer (LVDT) to sense its position. They are assembled in a custom mount that also contains the tip-tilt actuator and secondary mirror.

7.1 Encoder

The encoder is an RDPE Group D6/05000U LVDT. This encoder is a transformer coil that senses how far a ferrite rod is placed into its core. The sensing is contactless, has resolution limited only by the noise of the driving amplifier and the range is 10mm. However, like all LVDTs it has a null point within its range best avoided for precise measurements. There is sufficient mechanical adjustment available to move this null away from the focus position should the two overlap.

An RDPE group S7AC industrial signal conditioner provides drive signals to the LVDT and amplifies the output to a level suitable for digitisation by an analog I/O board. The CPU can then drive the picomotor until the secondary mirror is at the requested LVDT position.

7.2 Actuator and driver

The actuator is a New Focus 8301 picomotor, a piezoelectric motor that drives a worm gear that in turn pushes the secondary focus mechanism. It was chosen for its small size, light weight, stiffness and ability to hold position when unpowered.

The picomotor is driven by a New Focus 8703 driver, which sets the picomotor speed and direction according to the sign and magnitude of an analog input voltage. This voltage is set by an analog output on an analog I/O board under CPU control.

The analog I/O board is limited to an output range of 0 to 4V, so this is level shifted and amplified to a range of $\pm$4V for the 8703. This gives the focus a maximum velocity of about 10μm/s that is deliberately limited in hardware for safety and power consumption reasons.

The 8703 also accepts an enable signal, which is provided by a buffered digital output from an analog I/O board under CPU control. When enabled the 8703 draws significant power (up to 5W) so the CPU only enables it on the rare occasions when the focus needs to be changed.