A FLEXIBLE DATA ACQUISITION, CONTROL AND TELEMETRY SYSTEM FOR EXPERIMENTAL PAYLOADS

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ABSTRACT

Experimental science payloads vary greatly in design for the purpose of performing specialized tasks. As such, their supporting control, data acquisition and telemetry subsystems are often expensive custom designed units with specific abilities, thus limiting reuse.

This paper presents a payload control, data acquisition and telemetry system capable of providing a range of functionality to science payloads as a consequence of its accommodating architecture, programmability, and physical modular design. Details of the system and its capabilities are presented followed by an actual configuration of the system as the backbone of a micro-electro-mechanical-systems technology demonstration payload designed for suborbital flight.

KEYWORDS

Control, data acquisition, telemetry system.

INTRODUCTION

In the context of educational groups concerned with the development of new technologies, the design of supporting subsystems can impart a significant burden on limited resources, possibly disproportionate to the intended technology development. To circumvent the need to develop custom hardware to support each new technology development, subsystems that are modular, scalable and customizable are essential. Such systems promote reuse as they can be configured for a range of applications. A consequential benefit is that these systems mature and establish a heritage which improves operational understanding and confidence in purpose built hardware.

The subsystem presented herein combines payload control, data acquisition, and telemetry (PCT) features in support of the development of microsatellite technologies. More specifically, the system was developed as part of a larger project within the Microsatellite Program, Astronautics and Space Technology Division, at the University of Southern California (USC).

The context of the Microsatellite Program and the project (known as Traveler) for which the PCT system was originally designed dictated that it make use of generalized hardware capable of exceeding the initial requirements, with specific functional objectives such as data acquisition rates and payload control, obtained programmatically, that is, by software that can be downloaded to the PCT system. Designing the system to be modular would maximize the likelihood of successful integration to a variety of payloads, and the ability to support essentially any array of sensors.

Development tools for the electrical hardware consisted of standard breadboard kits and tools for prototyping. Schematics, PCB layout and manufacture were accomplished using ExpressPCB. Software for the microcontroller based PCT system was written in C using the Hi-Tech PICC-18 C compiler and downloaded to the microcontroller using Microchip's MPLAB In-Circuit-Debugger 2. As part of the development process, a computer program was written in Microsoft Visual Basic .NET to analyze the telemetry stream coming from the PCT system.

The production level system was tested for correct operation while experiencing (sequentially) low temperature, vibration, and vacuum environments. Details of the testing equipment, procedures and results are omitted from this paper.

This paper follows with an overview of the PCT system architecture, which identifies the key hardware modules, describes the functionality of each, and illustrates their connectivity. Following this, each module is described in detail. Important design decisions will be explained and main components identified. Prior to the conclusion, details of the PCT system implementation are presented illustrating how the generalized hardware has been configured for the micro-electro-mechanical-systems (MEMS) technology demonstration payload, Traveler.

SYSTEM ARCHITECTURE OVERVIEW

The PCT system consists of three separable modules providing the following functionality:

1. Signal conditioning module (SCM): provides the interface for sensors to connect to the PCT system and performs conditioning of the analog signals prior to analog-to-digital conversion so that the full range and resolution of the ADC is utilized.
2. Data acquisition module (DAM): is the most important module of the system and performs sensor sampling, analog-to-digital conversion (ADC), data formatting, telemetry, and payload control.
3. Power regulation module (PRM): provides several regulated voltage sources derived from a single supply voltage to the SCM, DAM and experimental science payloads; it includes its own voltage/current monitoring circuitry and over-current protection.

The three modules are connected by five through-board stacking connectors, providing 43 electrical connections between any two modules, for the distribution of power and analog signals. This architecture allows the boards to be stacked in any order. An assembly of the modules is shown diagrammatically in Figure 1, which emphasizes connections between modules and presents their external interfaces.

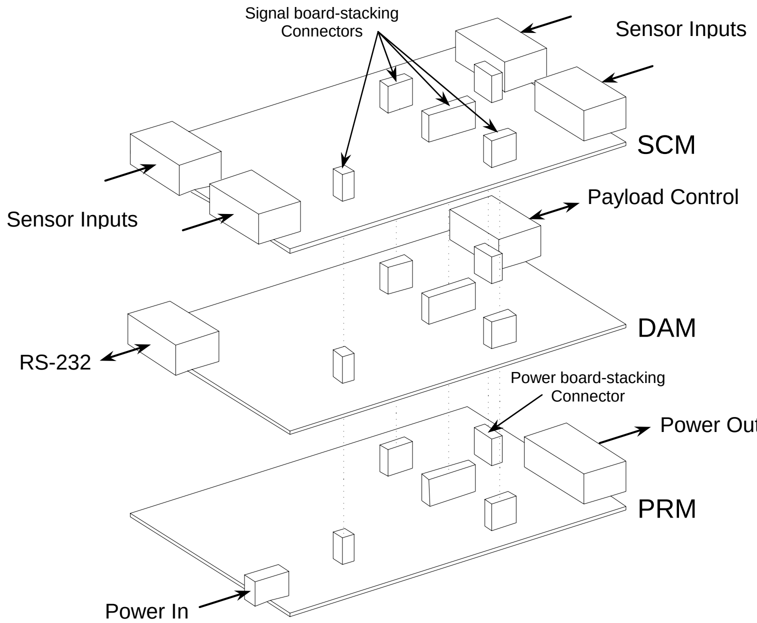

Figure 1: The PCT system identifying modules and interfaces.

SYSTEM DETAILS

Signal conditioning module (SCM)

Payload sensors such as thermocouples and pressure transducers are inputs to the SCM at one of four external connectors. The SCM routes those signals to the DAM, via signal conditioning circuitry, if required. In support of the Traveler project, the SCM provided conditioning of 11 J-type thermocouples, several of which are configured to measure temperatures below 0°C. This was achieved using Analog Devices AD594 thermocouple amplifier ICs, with a linear output of 10mV/°C. The AD594 includes the ability to offset the output voltage by a fixed margin. This feature was utilized to ensure positive voltages would be input to the ADC even if temperatures below 0°C were measured. The SCM is shown in Figure 2.

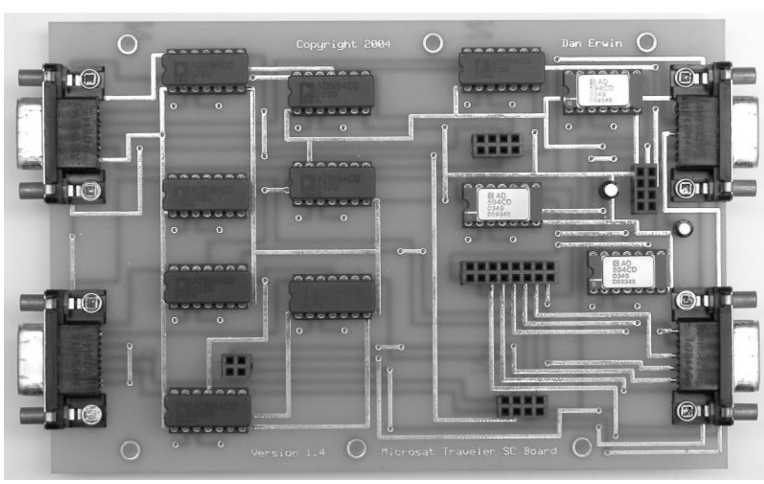

Figure 2: Signal conditioning module.

Data acquisition module (DAM)
The central processor of the DAM is a Microchip PIC 18F452 microcontroller, running at 40MHz. The microcontroller provides the telemetry interface in the form of an RS-232 serial port allowing direct connection to a PC or other data terminal equipment, including solid state memory devices and wireless transceivers. An I^2C bus connects a Microchip 24LC515 512KByte EEPROM, for storing calibration, configuration and status data, and Philips PCF8583 real-time-clock (RTC), for timed payload control operations, to the microcontroller. A total of eight 10-bit ADCs are provided by the microcontroller; three permanently measure health parameters (current, voltage and temperature) of the DAM, three are direct inputs from sensors, and the remaining two are connected to outputs of Maxim MAX306 high-speed analog multiplexers, each combining 16 analog channels. This configuration provides a total of 35 (free) plus 3 (fixed) analog signals for sampling. Payload control functionality is provided by 5 bi-directional digital IO lines, 2 of which support external interrupts, and one high-current relay switched output. Connections for a break-wire to trigger data acquisition are also provided. The module contains on-board +5V regulation (from a +12V supply), with associated voltage and current monitoring, and over-current protection. Ambient temperature is measured by an AD594.

Customized functionality of the generalized hardware is achieved by programming the microcontroller through an in-circuit serial programming (ICSP) interface. This provides a fast and convenient way to reprogram the system without having to remove it from its environment.

The DAM is shown in Figure 3.

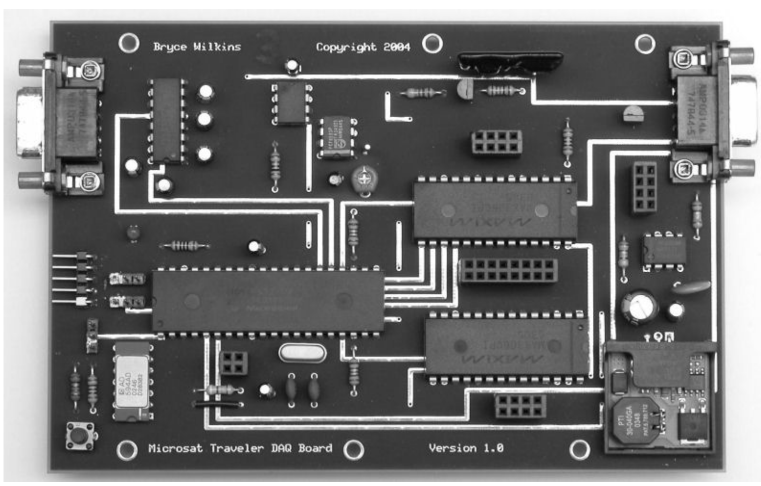

Figure 3: Data acquisition module.

Power regulation module (PRM)
This module receives as input a voltage in the range 25-38V and outputs regulated voltages of -5, +3, +5, and two at +12 volts. Each of the outputs can provide up to 1A, not all simultaneously, except for the +3V source which is limited to 400mA. The module contains its own current and voltage sensing circuitry, with output signals routed to the DAM. Current sensing is primarily by Maxim MAX471 ICs. Considering launch survivability and often inaccessible payloads, over-current protection is provided by self-resetting positive temperature coefficient (PTC) devices. The PRM is shown in Figure 4.

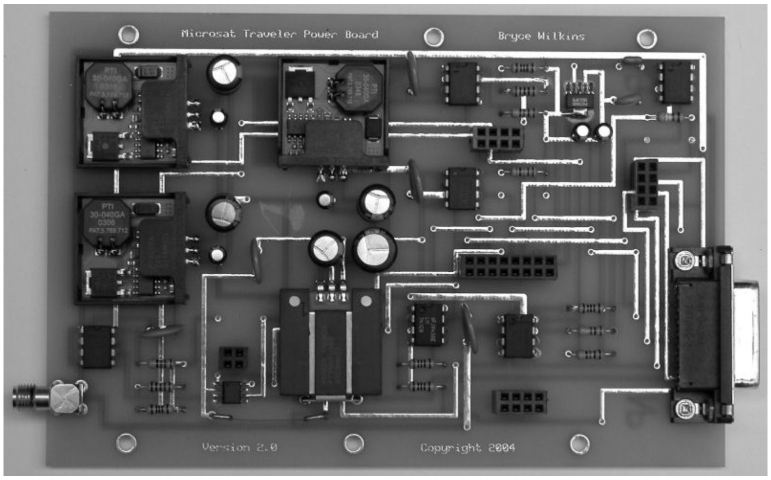

Figure 4: Power regulation module.

SYSTEM IMPLEMENTATION - TRAVELER

Traveler Overview

Traveler is a MEMS technology demonstration payload, designed and built at USC for the purpose of evaluating several MEMS components for space application. Traveler consists of five experimental MEMS devices: a free-molecule micro-resistojet (FMMR) electric propulsion device [1] and its associated propellant tank with micro-porous membrane, individual accelerometer and magnetometer, and Knudsen compressor [2].

Data Acquisition and Payload Control Configuration

Analog inputs of the DAM have been allocated to the payload sensors as follows:

Analog Signal	Signal Description	Analog Signal	Signal Description
Multiplexed ADC Inputs			
1	Health: +3V peripheral (voltage)	17	Prop Tank Thermocouple 1
2	Health: +3V peripheral (current)	18	Prop Tank Thermocouple 2
3	Health: -5V peripheral (voltage)	19	Prop Tank Continuity
4	Health: -5V peripheral (current)	20	FMMR Thermocouple 1
5	Health: +5V peripheral (voltage)	21	FMMR Thermocouple 2
6	Health: +5V peripheral (current)	22	FMMR Thermocouple 3
7	Health: +12V peripheral (voltage)	23	FMMR Thermocouple 4
8	Health: +12V peripheral (current)	24	Knudsen LED Detector
9	Health: +12V peripheral (voltage)	25	Knudsen Thermocouple 1
10	Health: +12V peripheral (current)	26	Knudsen Thermocouple 2
11	Health: +35V source (voltage)	27	Knudsen Pressure 1
12	Health: +35V source (current)	28	Knudsen Pressure 2
13	Health: Thermocouple 1	29	Magnetometer X axis
… continued …			

14	Health: Thermocouple 2	30	Magnetometer Y axis
15	Health: Thermocouple 3	31	Magnetometer Z axis
16	Health: Pressure	32	[unused]
Direct ADC Inputs			
33	Health: +5Vcomputer (voltage)	36	Accelerometer X axis
34	Health: +5V computer (current)	37	Accelerometer Y axis
35	Health: PCB Thermocouple	38	Accelerometer Z axis

Analog signals 1-16 are system health signals and are combined by one of the two multiplexers; signals 17-32 are science payload measurements and are combined by the second multiplexer. This arrangement is acceptable as sample rates for the multiplexed signals can be slow due to gradual changes in the physical quantities being measured. Signals 33-35 are direct inputs to ADCs on the DAM, and measure health signals of the DAM. Finally, signals 36-38, which are also direct inputs to ADCs, measure acceleration in three directions. By connecting the accelerometer directly to ADCs, the accelerometer can be sampled at a faster rate allowing for observation of high frequency vibration.

The payload control interface supported the experimental hardware as follows:

Signal Number	Signal Type	Usage
1	Relay In	Knudsen LED power
2	Relay Out	Knudsen LED power
3	Digital IO	[unused]
4	Breakwire In	[unused]
5	Digital IO	[unused]
6	Digital IO	[unused]
7	Breakwire Out	[unused]
8	Digital IO	Magnetometer Set/Reset
9	Digital IO	[unused]

Peripheral Device Configuration
The RTC is configured by software to interrupt the microcontroller at specified time intervals to command on/off an LED used as a heat source to drive the Knudsen compressor. The EEPROM is currently used to store operating status data such that if an intermittent power failure occurred leading to a PCT system reset, the last operating state could be recovered.

Telemetry Format and Configuration
The data format of the telemetry stream for Traveler was devised to detect missing frames, recover from corrupt/incomplete frames, and contain any number and combination of sensor data in each transmitted frame. To achieve this, the telemetry frame format implemented is as follows:

Frame Header						Frame Data Part						
'T'	'1'	x	FN	SB	n	ID1	H1	L1	…	IDn	Hn	Ln

In this diagram, each of the smaller boxes represents an unsigned 8-bit value; not every 8-bit value is valid for each cell. An explanation of each of the components of the frame follows:

- ‘T’, ‘1’: ASCII character values used to denote the start of a new telemetry frame. It was found to be sufficiently robust to assume that the two-character combination “T1” would never appear at any other location in the frame, and thus existed as a valid new frame identifier.
- x: Number of bytes remaining in current telemetry frame.
- FN: Frame number; used to track sequence of received data frames and identify missing frames.
- SB: Status; used to report current status of the PCT system.
- n: Number of sensor/data pairs that follow in the data part of the frame.
- IDn: Sensor identification number for the n^{th} sensor/data pair; identifies for which sensor the following data corresponds.
- Hn: High-byte of the ADC output corresponding to the n^{th} sensor previously identified.
- Ln: Low-byte of the ADC output corresponding to the n^{th} sensor previously identified.

The RS-232 telemetry system is connected at a baud rate of 19.2k, 8 data bits, no parity, 1 stop bit, and no handshaking, to the launch vehicle telemetry system, which receives data from the PCT system and upon incorporating it into its own telemetry, the data is transmitted to a ground station.

Telemetry Analysis Interface
As a supportive component of developing the telemetry system and to assist with debugging and interpreting data output by the PCT, a Visual Basic program was created. A screenshot of the graphical user interface (GUI) is presented in Figure 5. The program can read data directly from a serial port, or from an input file on disk.

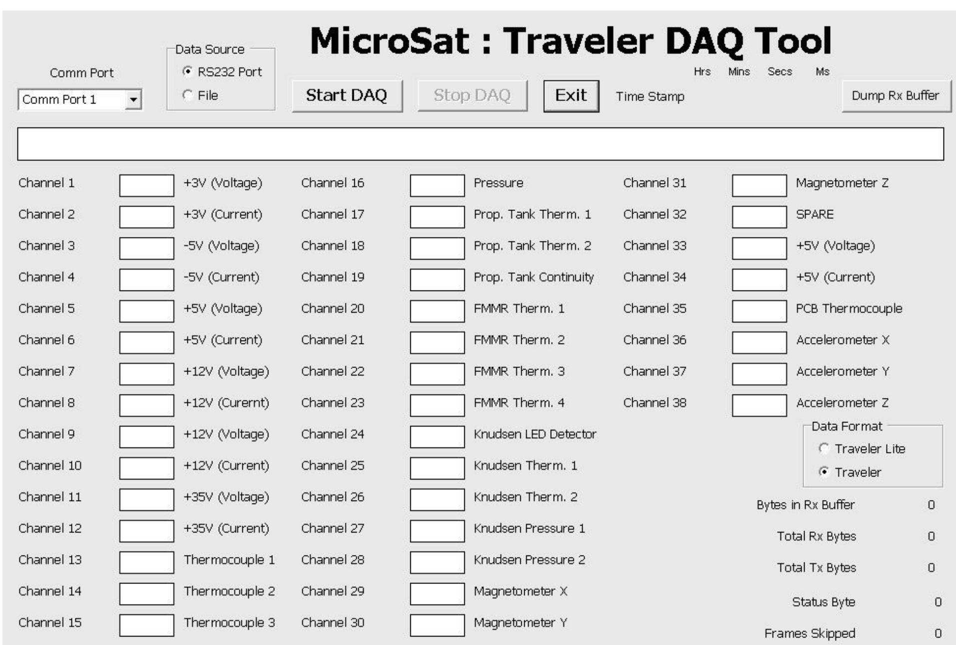

Figure 5: Visual Basic GUI for Traveler PCT system.

CONCLUSION

This paper has described a flexible payload control, data acquisition, and telemetry system with a range of functionality making it suitable for a variety of experimental science payloads. Reasons leading to its modular architecture and details of the system design have been presented, along with a descriptive implementation of the system.

Further use of this system with many experimental payloads will validate its true adaptability and identify limitations. Independently, its use will establish a history of successful component operation in a range of spaceflight conditions; the practical knowledge and lessons learned will be invaluable in the development of future space hardware.

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