Command and Data Handling: Design

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AA420 Space Design

Outline

- Driving Issues and Requirements
  - mission
  - sensors and actuators
  - communications
  - radiation
- Software approaches
  - simple versus OS
  - Protocols
- Types of Architectures
- Design Approach
- References:
  - Larson and Wertz
  - Stone, Harold E.; Microcomputer Interfacing; Addison-Wesley Publishing Company; Reading, MA; 1982.
  - Blau, Mike; C&DH SW Homepage, NASA TRACE project, http://sunland.gsfc.nasa.gov/~cdhsw/trace/cdhswtop.htm, 1996.
  - Questions to mentors

Driving Issues and Requirements

- Mission
  - amount, importance of science data
  - on-board calculations required
- Number, type, and rate of sensors and actuators
- Radiation
- Communication windows and the amount of data sent/received
- Vibration/thermal characteristics of boards
- Power required
- Complexity in software design
- Cost

Mission Objectives and Science Data

- The mission objectives and importance of the data collected drive the on-board memory type and size.
- Is the science data very important, such that it cannot be stored in RAM but requires radiation hardened memory or ROM?
- How many communication passes are there to downlink the data?
- How much data is required for downlink (and thus storage)?
- Is there on-board decision making or other high computationally intensive software?
  - Rendezvous closed loop system
  - video downlink
  - rendezvous sensors

Sensors and Actuators

- Sensors are required for
  - health (temperature, voltage, current, pressure, fuel,…)
  - decision making (attitude determination, navigation and rendezvous)
- Each sensor must have a
  - type (digital or analog)
  - data rate
  - word size
  - number of sensors
- A table of sensors and each of the above characteristics should be started asap

Example: Dawgstar Sensors

Item	Telemetry Type	Quantity	Sampling Rate (Hz)	Word Size (bits)	Required Data Rate (bps)
Power					
Solar cell voltage in sensor	voltage	1	1	8	8
Power bus voltage out sensor	voltage	1	1	8	8
Battery charge sensor	voltage	1	1	8	8
Power Management		1	1	8	8
Thermal					
PRT sensor	temperature	2	0.1	16	3.2
Thermal Control	heaters	1	0.1	8	0.8
Communications					
GPS power level sensor	voltage	1	1	8	8
GPS temperature sensor	temperature	1	1	8	8
Antenna temp	temperature	1	1	8	8
Transmit Power	voltage	2	1	8	16
Kalman Filter	GPS	1	0.01	16	0.16
C&DH					
CPU power level sensor	voltage	1	1	8	8
CPU temperature sensor	temperature	1	1	8	8
Fault Detection Monitor	error detection	1	5	8	40
Fault Correction	error correction	1	5	8	40
Telemetry Processing	system health	1	10	8	80
Command Processing	system management	1	10	8	80
Propulsion					
Capacitor voltage sensor	voltage	4	10	8	320
Propellant sensor	voltage	8	2	8	128
D.I. Capacitor sensor	voltage	8	5	8	320
ADCS					
Magnetometer	xyz position	1	10	16	160
Gyro	xyz rotation	1	10	8	80
Horizon Sensor	pitch and roll	2	10	8	160
Temperature sensor	temperature	4	10	8	320
Thruster Control	thruster control	8	1	8	64
Orbit Propagation	orbit determination	1	1	8	8
Error Detection	Orbit error	1	1	8	8
Science					
Absolute electron density		1	70	16	1120
Impedance data		1	0.7	16	11.2
			PCM Data Rate (bps)		3031.36

Radiation

- Radiation can work in primarily two ways:
  1. Single Event Upsets - usually a bit flip (software) or a hardware anomaly (latchup) caused by a short burst of radiation (such as a solar flair). Latchups are much more dangerous.
  2. Constant bombardment of radiation over time

- Single event upsets are usually helped by
  - using a WatchDog timer on the CPU
  - using a second CPU to watch the primary
- Constant bombardment is a function of
  - location in space
  - time of mission

  neither of which should affect our mission
- Radiation Hardened components can help with both types of radiation, but they are VERY expensive (>$30K)

Other Issues

- Communication windows (i.e. how long can we talk) and power drive the amount of data that can be sent to the ground.
  - This is a big system driver for small satellites in LEO
- Downlink options for Universities:
  - own ground station
  - other universities
  - purchase time from commercial ground stations
- Vibration/thermal characteristics of boards
  - are they classified as MIL spec?
  - High thermal loads on boards is an important driver
- How much continuous power is required for the board?
- What is the cost of the board?
- What is the mass of the board
  - including wiring?

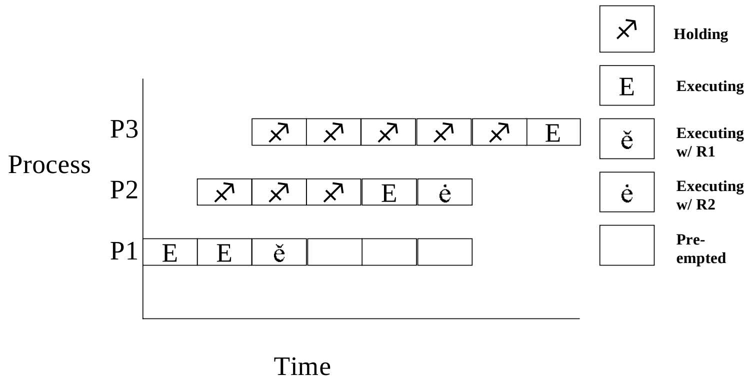
Dawgstar Requirements

Hardware Capabilities	
Digital I/O Lines 48 – 24	48 - 4
RS-232 in addition to above lines	4
Analog Input Signals	64 - 8
bus width / addressable memory space	25-bit or higher
Boot Image Memory	256k (Fuse-Link ROM on flight board, EEPROM on development boards)
System Memory	1 MB
FIFO Data Memory	8 MB
Processor Speed	20 – 15 MHz
Operating Environment	
Industry Standard Compliance	Mil-Spec 883, Level B NOTE: compliance with this standard is equivalent to the requirements listed below.
Operating Temperature	-55 to +85 C
Cooling Mechanism	Conduction cooled
Structural Stability	40g shock loads, 12g RMS random vibe
Total Radiation Dose	20 – 10 krad
Single Event Upset Threshold	40 – 20 MeV/mg/cm2
SEU Error Rate	10E-10 – 10E-8 errors/bit/day
Hardware Watchdog Timer	2-1
Development, Support, etc.	
VxWorks OS Support	
1 Flight Board, 3 Development boards	
Lead Times: 2 weeks for development boards, 6 months for flight board	
Educational Discount	
Physical Characteristics	
Mass	0.1 kg
Power consumption	0.8 – 1.2 W

Simple Software Design: "Loop"

- While "Spacecraft OK"
  - sample attitude sensors
  - sample health sensors
  - sample navigation and other science sensors
  - save health and science sensors to off-board memory queue
  - calculate attitude command
  - calculate position command
  - send out commands to attitude actuators
  - send out commands to propulsion
- End
- Interrupt for:
  - communications
  - anomalies

Operating System: Scheduling of Tasks



- A operating system:
  - is more complex than a simple scheme
  - allows easy multi-tasking

Communication Protocols and Information Flow

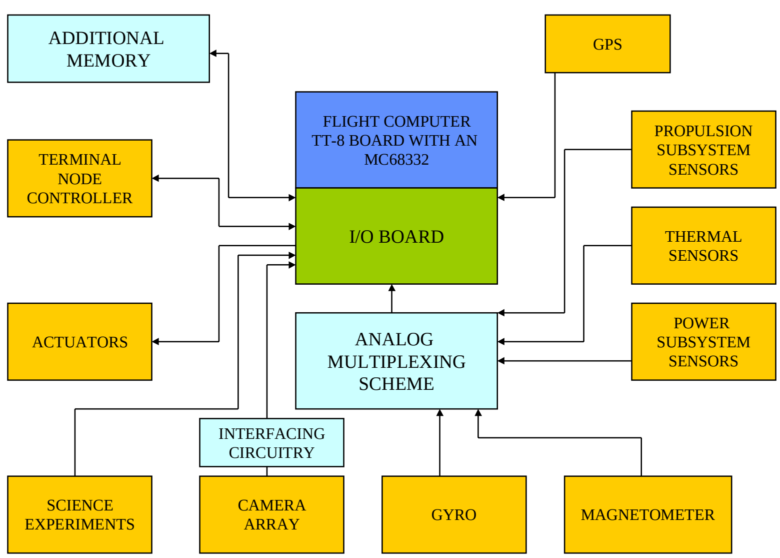
- A Terminal Node Controller (TNC) packetizes binary serial data into a communications protocol format.
- An alternative is an internal modem in the transmitter/receiver
- After packetizing the data, the TNC modulates it using frequency shift keying (FSK)
- Frames and packets are two methods of formatting data for storage and transmission
  - frames are fixed
  - packets are variable
- Packets add flexibility to the telemetry system
  - Each major subsystem can package its data differently
  - Data can be transmitted as generated
  - Standard communication protocols can be used
  - many EDAC software exists
- Examples
  - X.25, TCP/IP, ETHERNET

AX.25 Packet Structure

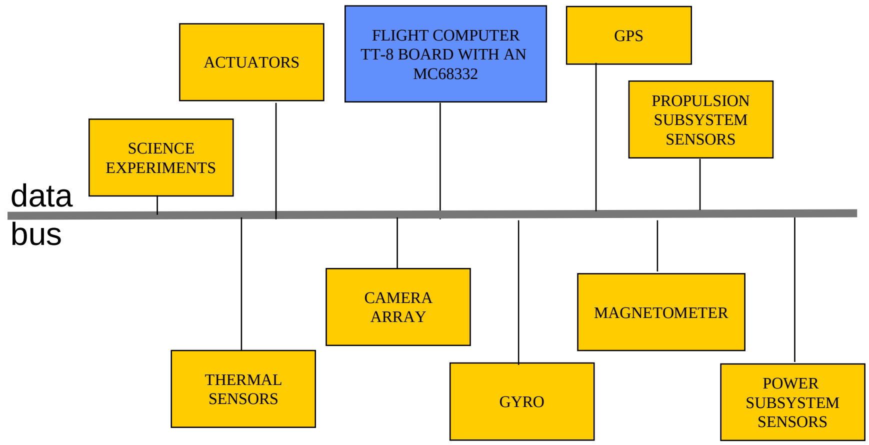
```
##########################################################################
# Packet ID #RT Bit #                    DATA                    #  CRC    #
##########################################################################
```

- Packet ID: Identifies which satellite is sending the data
- RT Bit: Real Time bit identifies whether the data is real time, or processed data
- Data: Data field (larger field means faster transfer, but more risk)
- CRC: allows the satellite to determine if the packet has been corrupted

Centralized Architecture



Distributed Architecture

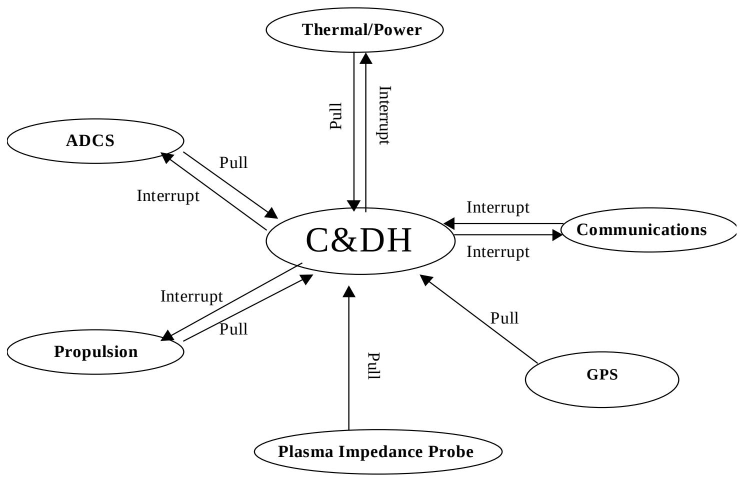


- Data bus supports all data for the system
- components are nodes that use standard communication protocols to exchange data, interrupt
- usually a parallel network of wires

Software Issues

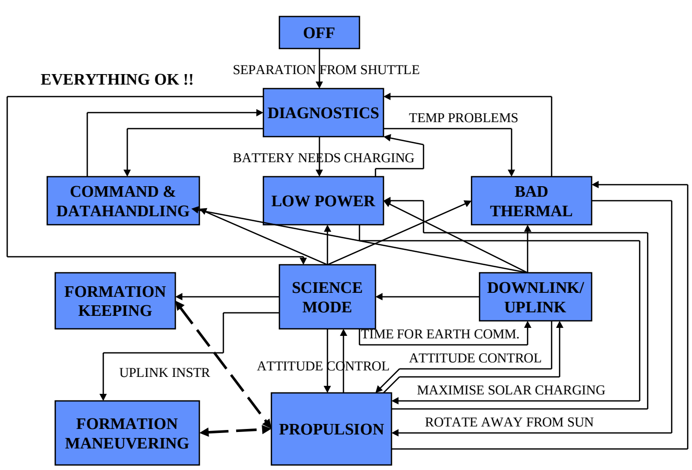
- How does information flow:
  - serially
  - pull
  - interrupt
- Mission goals, cost requirements will drive the decision of using an operating system
- The best approach to software design is to define “modes of operation”
  - initial checkout
  - diagnostic
  - nominal attitude control
  - rendezvous
  - docking
  - servicing
  - ...

How the CPU gets Information



- The two most common approaches are pulling data (i.e. sampling when the CPU requires data) and interrupt.

C&DH: Functional Diagram



C&DH: States of operation

Diagnostics

- Check battery charge
- Check temperature sensors
- Everything OK - go to science mode

Science Mode

- Attitude control
  - gyroscope, magnetometer, camera
- Science measurements
- Health monitoring
- GPS and Crosslink monitoring

Low Power

- DAWGSTAR is in light
  - orient to max solar intake
  - shut down inessentials while charging
- DAWGSTAR is cold
  - sleep till light side

Bad Thermal

- Low temperature
  - use heaters
- Excessive temperature
  - shut down device
  - rotate away from sun

C&DH: States of operation (cont.)

Propulsion

- Attitude and position determined before entering propulsion state
- Fire thrusters *1, 2, ..., n* for *x* seconds

Formation maneuvering

- Based on GPS, Crosslink, and Uplink instructions
- Only a few times during mission duration
- Attitude Control

Downlink / Uplink Mode

- Uplink instructions to memory address
- Downlink data from memory address
- Health monitoring
- Attitude Control

Formation Keeping

- Based on GPS and Crosslink data
- Attitude Control

Design Approach

- List design drivers, associated calculations, narrow requirements
- Fill out more detailed specification based on template, list the requirements for your system
- Make a table of the sensors, data rates, numbers, type
- List modes of operation
- Estimate processing required for each mode of operation
- Using specifications, do a trade study on the different commercial off the shelf board options
  - you may need to make some small changes to the board, such as added RS-232 ports
  - remember MUXing!
- Purchase a board a start the initial prototyping (remember lead time!)