A Lightweight Open Source Command and Control Center and its Interface to Cubesat Flight Software

• Patrick H. Stakem

Capitol Technology University

Johns Hopkins University

• Guilherme Korol

Pontifical University Catholic of Rio Grande do Sul, Porto Alegre

U. C. Denver

• Gabriel Augusto Gomes

U. C. Colorado Springs

Sao Paulo State Technical College (FATEC-BS)

Summer 2015 Student Project

- Cubesat Engineering and Cubesat Operations Courses at Capitol Technology University, Laurel, MD. 8-week session.
- 20 senior undergraduates, 19 from the Brazilian Scientific Mobility Program.
- Goal: Learn good system engineering practices and the unique challenges of the space environment. Build, test, and operate a Cubesat.

Cubesat

- Volume of 1 liter (10 cm cube) 1U.
- Mass not to exceed 1.33 kg.
- COTS components.
- Compatible with any launch vehicle.
- Typically replaces ballast (sand).
- Free flyer or attached to Space Station.
- Limited life. Extremely limited downlink.
- Individual, high school, college, professional project.
- Used to increase the TRL for instruments inexpensively.
- Huge commercial infrastructure.

Our Flight Computer

Raspberry Pi 2 Mod B

- 32-bit, quad core, 900MHz; ARM v7 architecture.
- 1 Gigabyte SRAM; microSD card.
- 4 x usb; Ethernet; 40 GPIO.
- 5 volt operation
- 42 grams; 2.2 x 3.4 inches. $30.
- rad-hard: not bad - login accepted up to 150krad(si).

Flight Software

- Raspian Linux, a derivative of the Debian distribution.
- Not real-time, but can be modified with non-preemption patch and real-time patch.
- Add on a real time clock (another $5.)
- Hosts cFS – core Flight System.
- Application code in Python and c.

Core Flight System

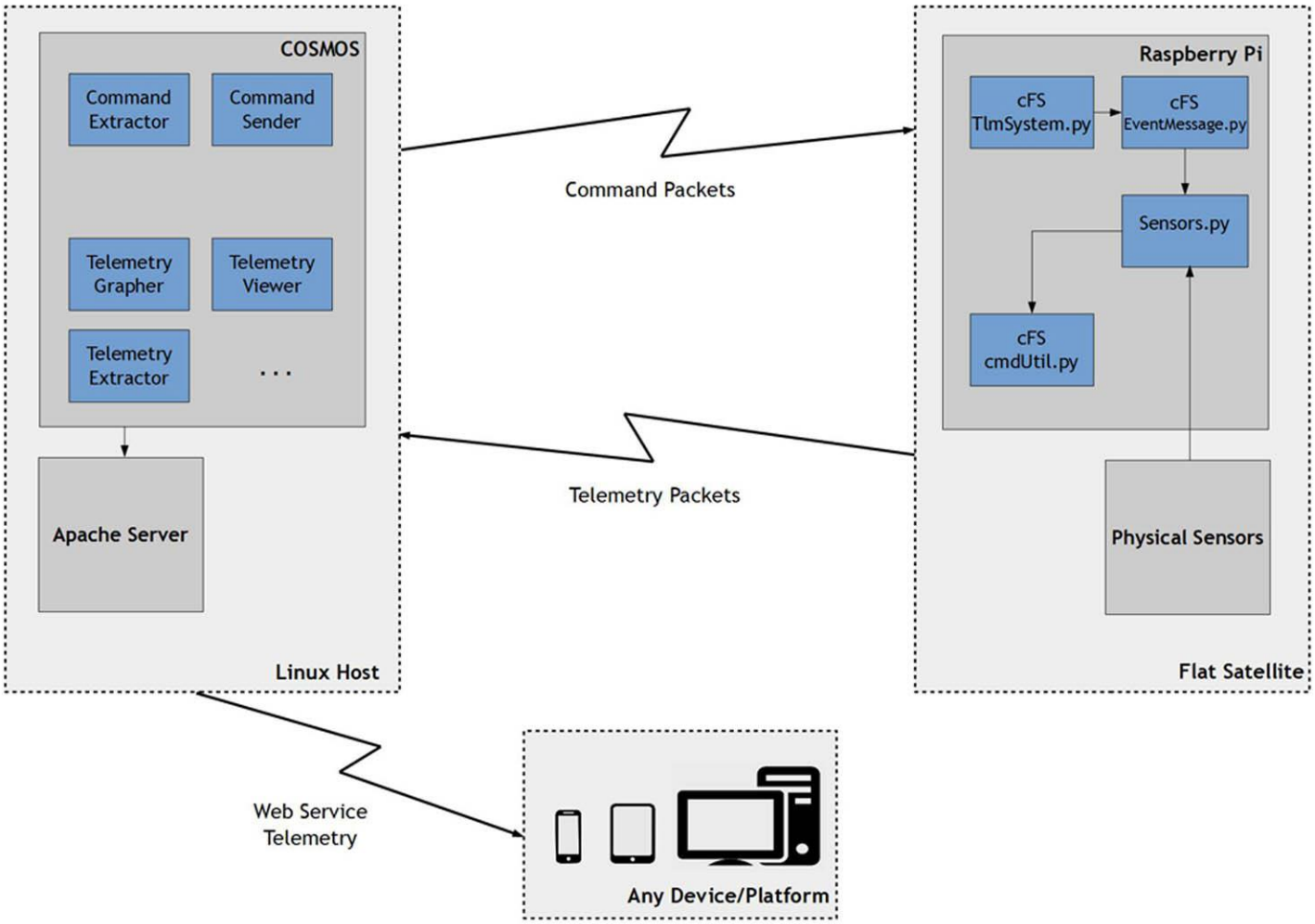
- From NASA/GSFC.
- Released under the NASA Open Source agreement.
- An application suite of flight software.
- 12 C&DH applications.
- Flown on GPM (Global Precipitation Measurement), LADEE (Lunar Atmosphere and Dust Environmental Explorer) missions, among others.

cFS apps

- Checksum
- File Manager (FM)
- Stored Command (SC)
- Limit Checker (LC)
- Memory Manager
- Memory Dwell
- Scheduler
- CCSDS File Delivery Protocol
- Data Storage (DS)
- Housekeeping (HK)
- Health and Safety
- Software Bus Network

cFS usage and custom code

- TLMsystem.py
- EventMessage.py
- CmdUtil.c
- Sensors.py – a message service. Reads the sensors, interfaces with cFS tools for cmd and tlm.


COSMOS
Command Extractor
Command Sender
Telemetry Grapher
Telemetry Viewer
Telemetry Extractor
...
Apache Server
Linux Host
Command Packets
Telemetry Packets
Raspberry Pi
cFS TlmSystem.py
cFS EventMessage.py
Sensors.py
cFS cmdUtil.py
Physical Sensors
Flat Satellite
Web Service Telemetry
Any Device/Platform

CapTechU Control Center

- Space Operations Institute
- Established 2002 under a NASA Grant.
- Pc-based. Dozen seats
- Connected to GSFC via high speed line.
- Used for mission controller training.

Ground System Software

- Cosmos, from Ball Aerospace, Boulder, Co.
- Open Source, ITAR compliant.
- Our version built by an ex-grad student, now working at NASA/GSFC, as a volunteer, and posted back to Ball's area on github.
- Runs under Ubuntu Linux 14.04 (other versions available).
- Version verified by CapTechU students.
- Integrated Apache web server.

Ground system, continued

- Hosted on my old laptop. Lenovo R-61, 1.8 Gz Celeron, 1.5 G ram.
- Communicates with the Cubesat. Command and telemetry.
- Serves out telemetry over the internet.
- Individual user can use their laptop, tablet, or smart phone.
- Generates text messages for red alerts.

COSMOS (selected) aps

- Launcher
- Cmd and tlm
- Replay
- Limits monitor
- Command sender
- Script runner
- Packet viewer
- Tlm viewer
- Tlm grapher
- Data viewer
- Tlm extractor
- Command extractor

Web server

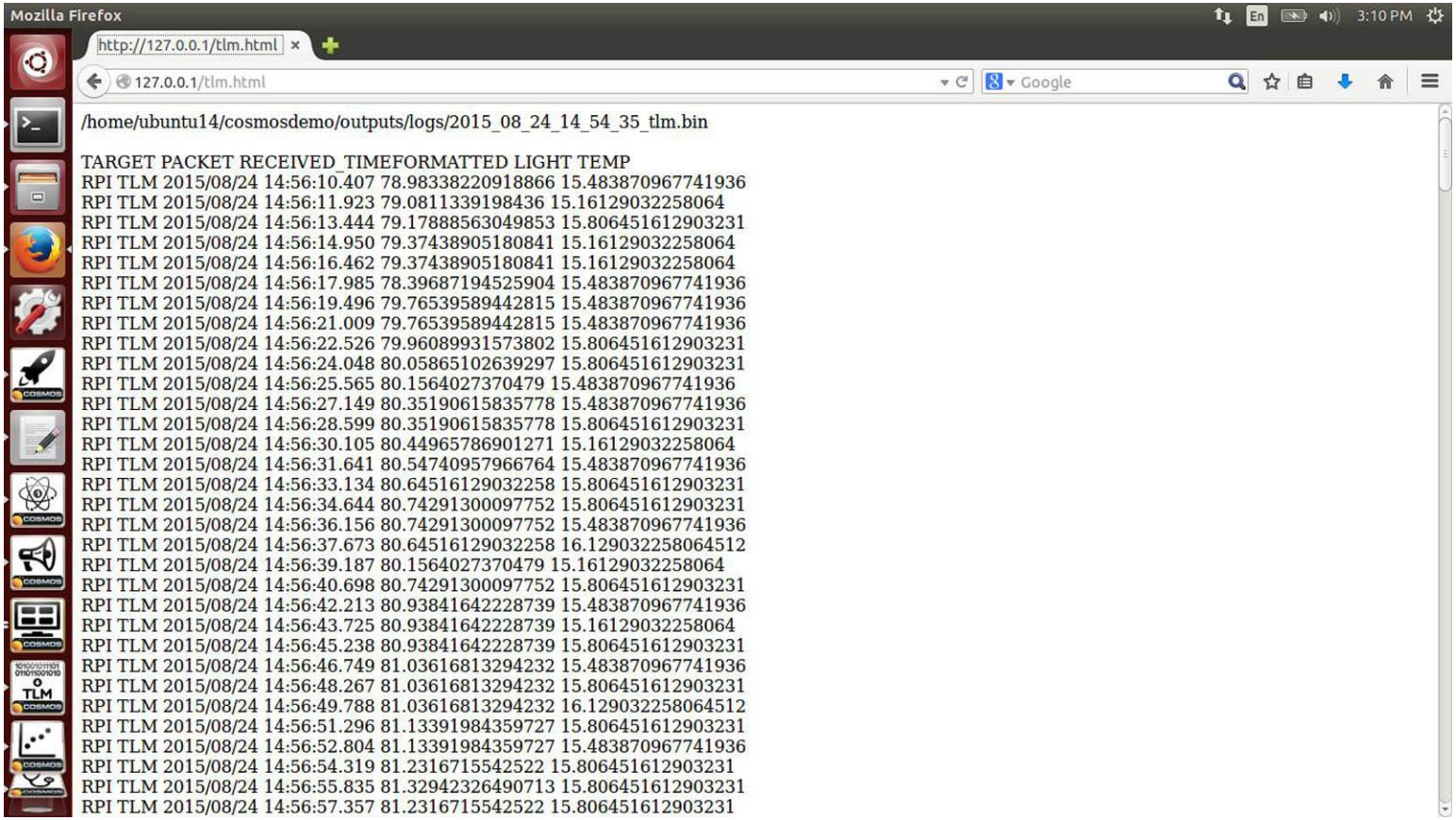
- Running on the same machine as COSMOS
- Apache Web Server (open source)
- We linked the COSMOS telemetry extractor to Apache. Converted text to HTML.

Advantages of this approach

- Support low-cost missions with low cost software and hardware, both in orbit and on the ground.
- Open source = flexibility of adoption and expansion.
- New Paradigm evolving – operate the satellite control center “dark.”
- Subsystem engineers get their telemetry on their own web page.
- System engineer (team lead) has visibility of all the data; controls commanding.

Advantages, continued

- Relevant subsystem engineer gets alerts via text or email regarding potential problems.
- Expand role of the limits checker to that of a virtual team member. Make it smarter. Do trending. Cross-discipline correlation.
- A collaborative, global project paradigm.
- Evolves to “Control Center as a service.”
- Cubesats use uplink and downlink as a service, now.


Mozilla Firefox
3:10 PM
http://127.0.0.1/tlm.html
127.0.0.1/tlm.html
Google
/home/ubuntu14/cosmosdemo/outputs/logs/2015_08_24_14_54_35_tlm.bin
TARGET PACKET RECEIVED_TIMEFORMATTED LIGHT TEMP
RPI TLM 2015/08/24 14:56:10.407 78.98338220918866 15.483870967741936
RPI TLM 2015/08/24 14:56:11.923 79.0811339198436 15.16129032258064
RPI TLM 2015/08/24 14:56:13.444 79.17888563049853 15.806451612903231
RPI TLM 2015/08/24 14:56:14.950 79.37438905180841 15.16129032258064
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RPI TLM 2015/08/24 14:56:19.496 79.76539589442815 15.483870967741936
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RPI TLM 2015/08/24 14:56:45.238 80.93841642228739 15.806451612903231
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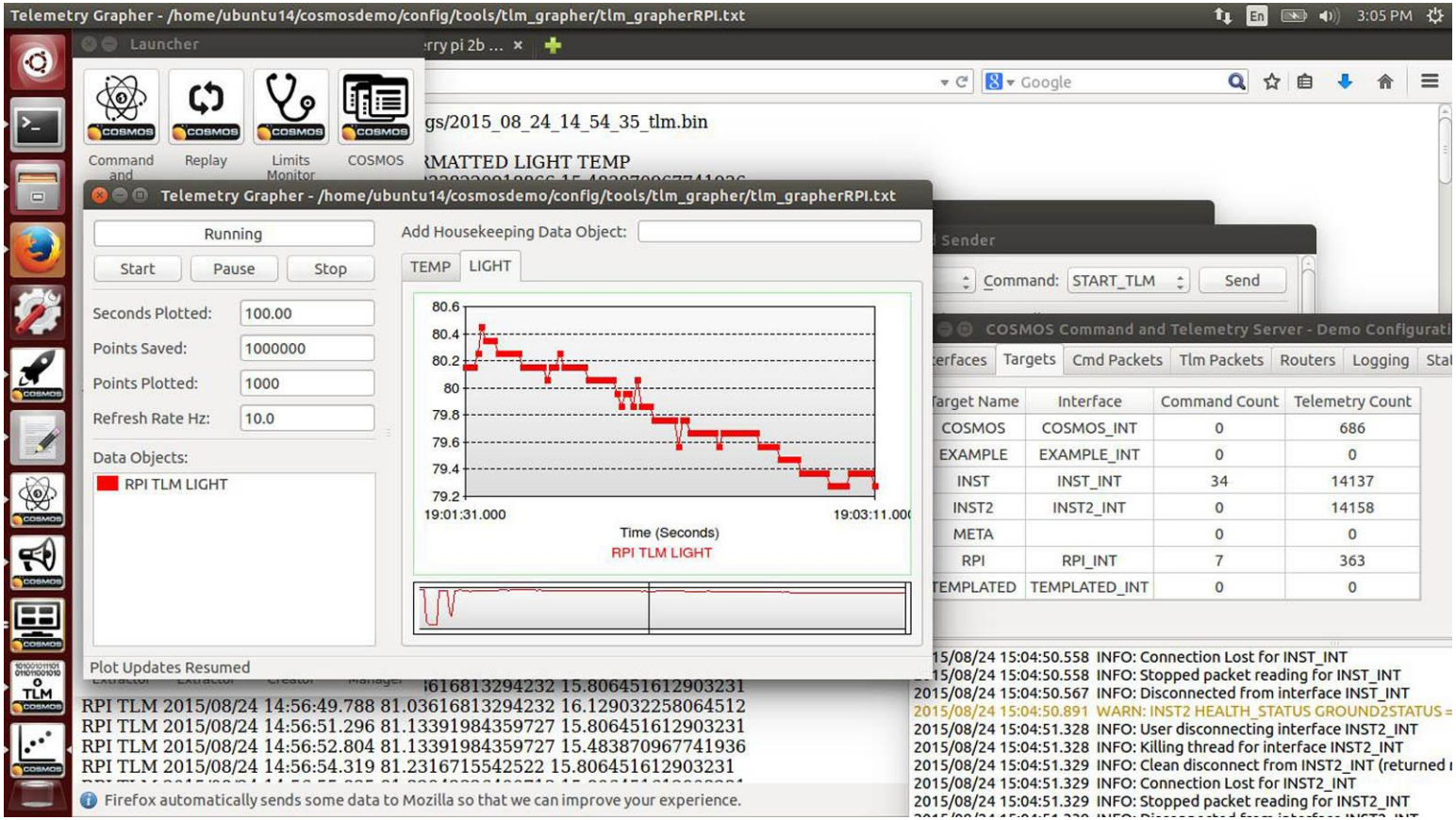
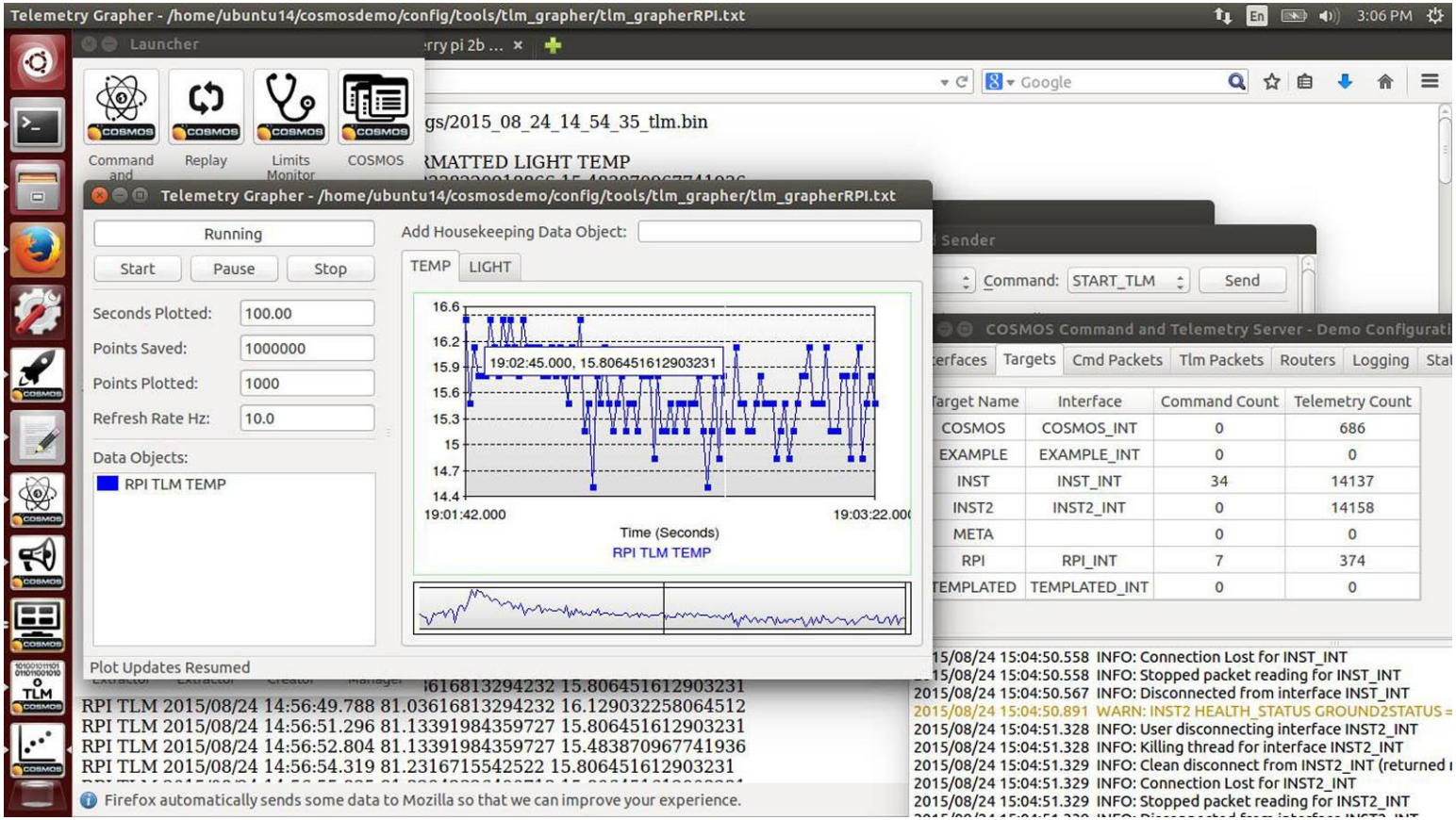
RPI TLM 2015/08/24 14:56:51.296 81.13391984359727 15.806451612903231
RPI TLM 2015/08/24 14:56:52.804 81.13391984359727 15.483870967741936
RPI TLM 2015/08/24 14:56:54.319 81.2316715542522 15.806451612903231
RPI TLM 2015/08/24 14:56:55.835 81.32942326490713 15.806451612903231
RPI TLM 2015/08/24 14:56:57.357 81.2316715542522 15.806451612903231


Telemetry Grapher - /home/ubuntu14/cosmosdemo/config/tools/tlm_grapher/tlm_grapherRPI.txt
Launcher
Command and
Replay
Limits Monitor
COSMOS
Telemetry Grapher - /home/ubuntu14/cosmosdemo/config/tools/tlm_grapher/tlm_grapherRPI.txt
Running
Start
Pause
Stop
Seconds Plotted: 100.00
Points Saved: 1000000
Points Plotted: 1000
Refresh Rate Hz: 10.0
Data Objects:
RPI TLM LIGHT
Add Housekeeping Data Object:
TEMP
LIGHT
80.6
80.4
80.2
80
79.8
79.6
79.4
79.2
19:01:31.000
Time (Seconds)
RPI TLM LIGHT
Plot Updates Resumed
Command: START_TLM
Send
COSMOS Command and Telemetry Server - Demo Configurati
Targets
Cmd Packets
Tlm Packets
Routers
Logging
Target Name | Interface | Command Count | Telemetry Count
COSMOS | COSMOS_INT | 0 | 686
EXAMPLE | EXAMPLE_INT | 0 | 0
INST | INST_INT | 34 | 14137
INST2 | INST2_INT | 0 | 14158
META | | 0 | 0
RPI | RPI_INT | 7 | 363
TEMPLATED | TEMPLATED_INT | 0 | 0
RPI TLM 2015/08/24 14:56:49.788 81.03616813294232 16.129032258064512
RPI TLM 2015/08/24 14:56:51.296 81.13391984359727 15.806451612903231
RPI TLM 2015/08/24 14:56:52.804 81.13391984359727 15.483870967741936
RPI TLM 2015/08/24 14:56:54.319 81.2316715542522 15.806451612903231
2015/08/24 15:04:50.558 INFO: Connection Lost for INST_INT
2015/08/24 15:04:50.558 INFO: Stopped packet reading for INST_INT
2015/08/24 15:04:50.567 INFO: Disconnected from interface INST_INT
2015/08/24 15:04:50.891 WARN: INST2 HEALTH_STATUS GROUND2STATUS =
2015/08/24 15:04:51.328 INFO: User disconnecting interface INST2_INT
2015/08/24 15:04:51.328 INFO: Killing thread for interface INST2_INT
2015/08/24 15:04:51.329 INFO: Clean disconnect from INST2_INT (returned
2015/08/24 15:04:51.329 INFO: Connection Lost for INST2_INT
2015/08/24 15:04:51.329 INFO: Stopped packet reading for INST2_INT
Firefox automatically sends some data to Mozilla so that we can improve your experience.


Telemetry Grapher - /home/ubuntu14/cosmosdemo/config/tools/tlm_grapher/tlm_grapherRPI.txt
Launcher
Command and
Replay
Limits Monitor
COSMOS
Running
Start
Pause
Stop
Seconds Plotted: 100.00
Points Saved: 1000000
Points Plotted: 1000
Refresh Rate Hz: 10.0
Data Objects:
RPI TLM TEMP
Add Housekeeping Data Object:
TEMP
LIGHT
19:02:45.000, 15.806451612903231
Time (Seconds)
RPI TLM TEMP
Plot Updates Resumed
RPI TLM 2015/08/24 14:56:49.788 81.03616813294232 16.129032258064512
RPI TLM 2015/08/24 14:56:51.296 81.13391984359727 15.806451612903231
RPI TLM 2015/08/24 14:56:52.804 81.13391984359727 15.483870967741936
RPI TLM 2015/08/24 14:56:54.319 81.2316715542522 15.806451612903231
Firefox automatically sends some data to Mozilla so that we can improve your experience.
Command: START_TLM
Send
COSMOS Command and Telemetry Server - Demo Configurati
Targets
Cmd Packets
Tlm Packets
Routers
Logging
Target Name | Interface | Command Count | Telemetry Count
COSMOS | COSMOS_INT | 0 | 686
EXAMPLE | EXAMPLE_INT | 0 | 0
INST | INST_INT | 34 | 14137
INST2 | INST2_INT | 0 | 14158
META | | 0 | 0
RPI | RPI_INT | 7 | 374
TEMPLATED | TEMPLATED_INT | 0 | 0
2015/08/24 15:04:50.558 INFO: Connection Lost for INST_INT
2015/08/24 15:04:50.558 INFO: Stopped packet reading for INST_INT
2015/08/24 15:04:50.567 INFO: Disconnected from interface INST_INT
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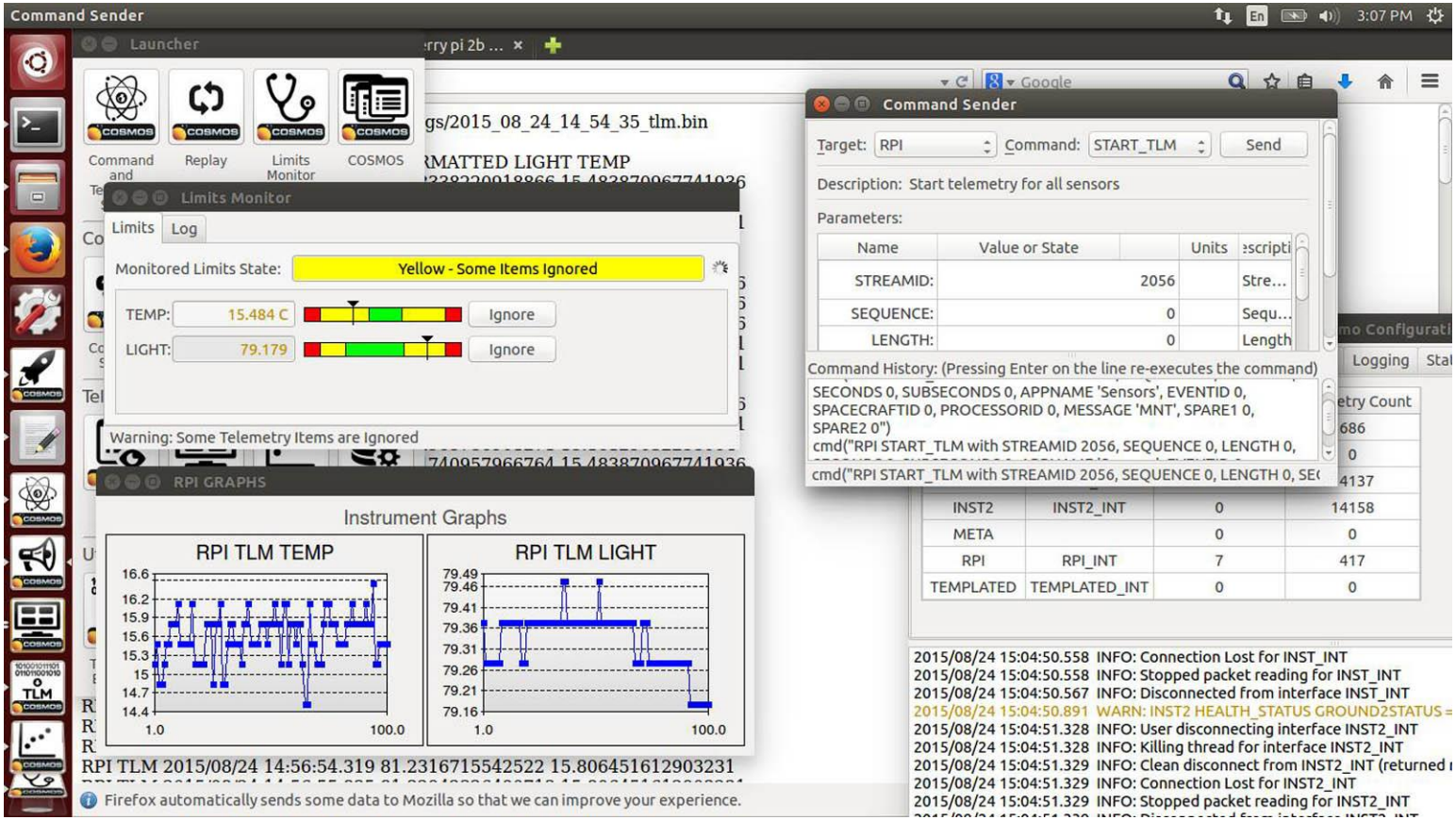
Command Sender
3:07 PM
Launcher
Command and
Replay
Limits Monitor
COSMOS
Limits Monitor
Limits
Log
Monitored Limits State:
Yellow - Some Items Ignored
TEMP:
15.484 C
Ignore
LIGHT:
79.179
Ignore
Warning: Some Telemetry Items are Ignored
RPI GRAPHS
Instrument Graphs
RPI TLM TEMP
RPI TLM LIGHT
RPI TLM 2015/08/24 14:56:54.319 81.2316715542522 15.806451612903231
Firefox automatically sends some data to Mozilla so that we can improve your experience.
Command Sender
Target:
RPI
Command:
START_TLM
Send
Description: Start telemetry for all sensors
Parameters:
Name
Value or State
Units
STREAMID:
2056
SEQUENCE:
0
LENGTH:
0
Command History: (Pressing Enter on the line re-executes the command)
SECONDS 0, SUBSECONDS 0, APPNAME 'Sensors', EVENTID 0,
SPACECRAFTID 0, PROCESSORID 0, MESSAGE 'MNT', SPARE1 0,
SPARE2 0")
cmd("RPI START_TLM with STREAMID 2056, SEQUENCE 0, LENGTH 0,
cmd("RPI START_TLM with STREAMID 2056, SEQUENCE 0, LENGTH 0, SE(
Logging
Count
INST2
INST2_INT
0
14158
META
0
0
RPI
RPI_INT
7
417
TEMPLATED
TEMPLATED_INT
0
0
2015/08/24 15:04:50.558 INFO: Connection Lost for INST_INT
2015/08/24 15:04:50.558 INFO: Stopped packet reading for INST_INT
2015/08/24 15:04:50.567 INFO: Disconnected from interface INST_INT
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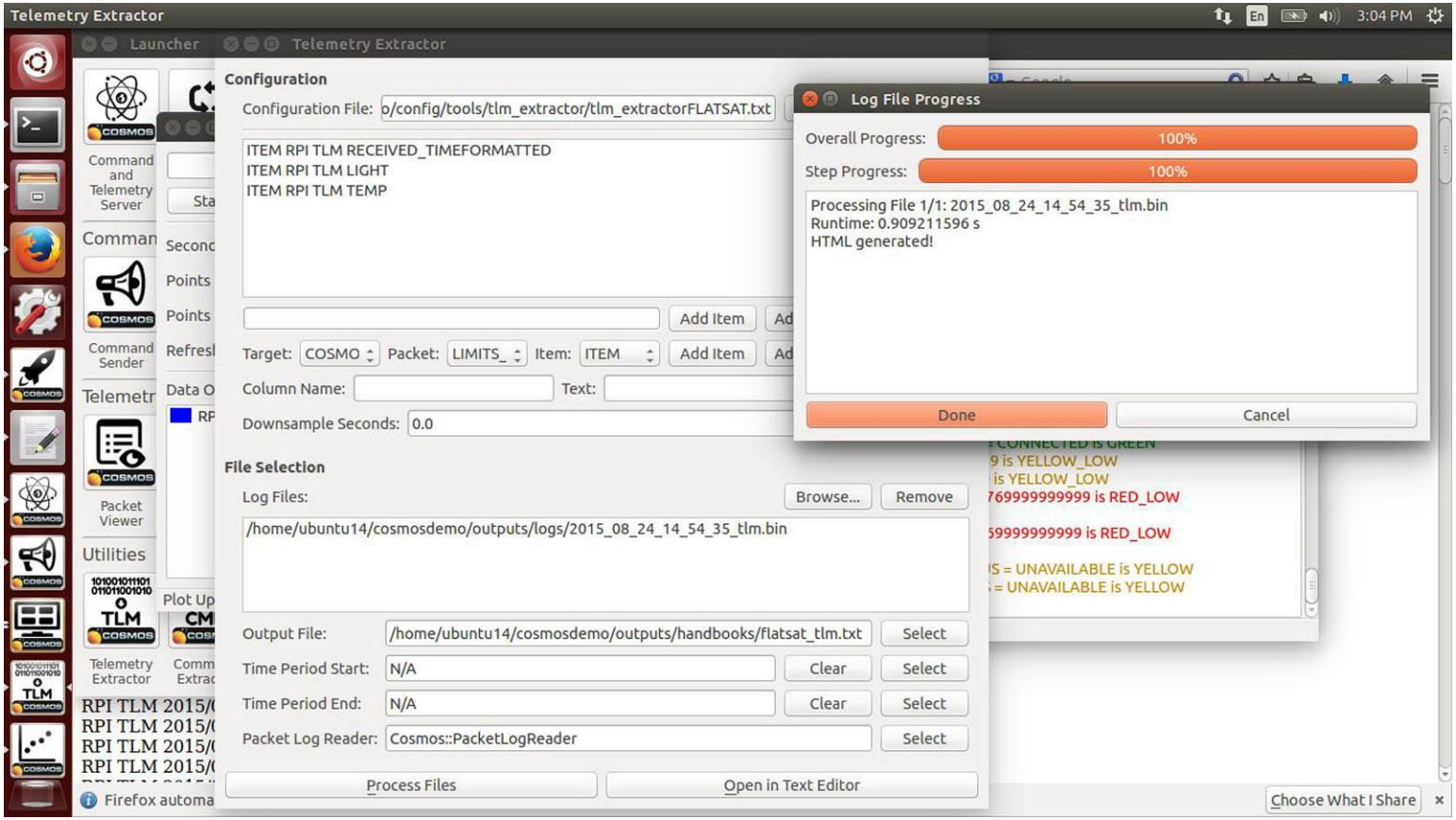
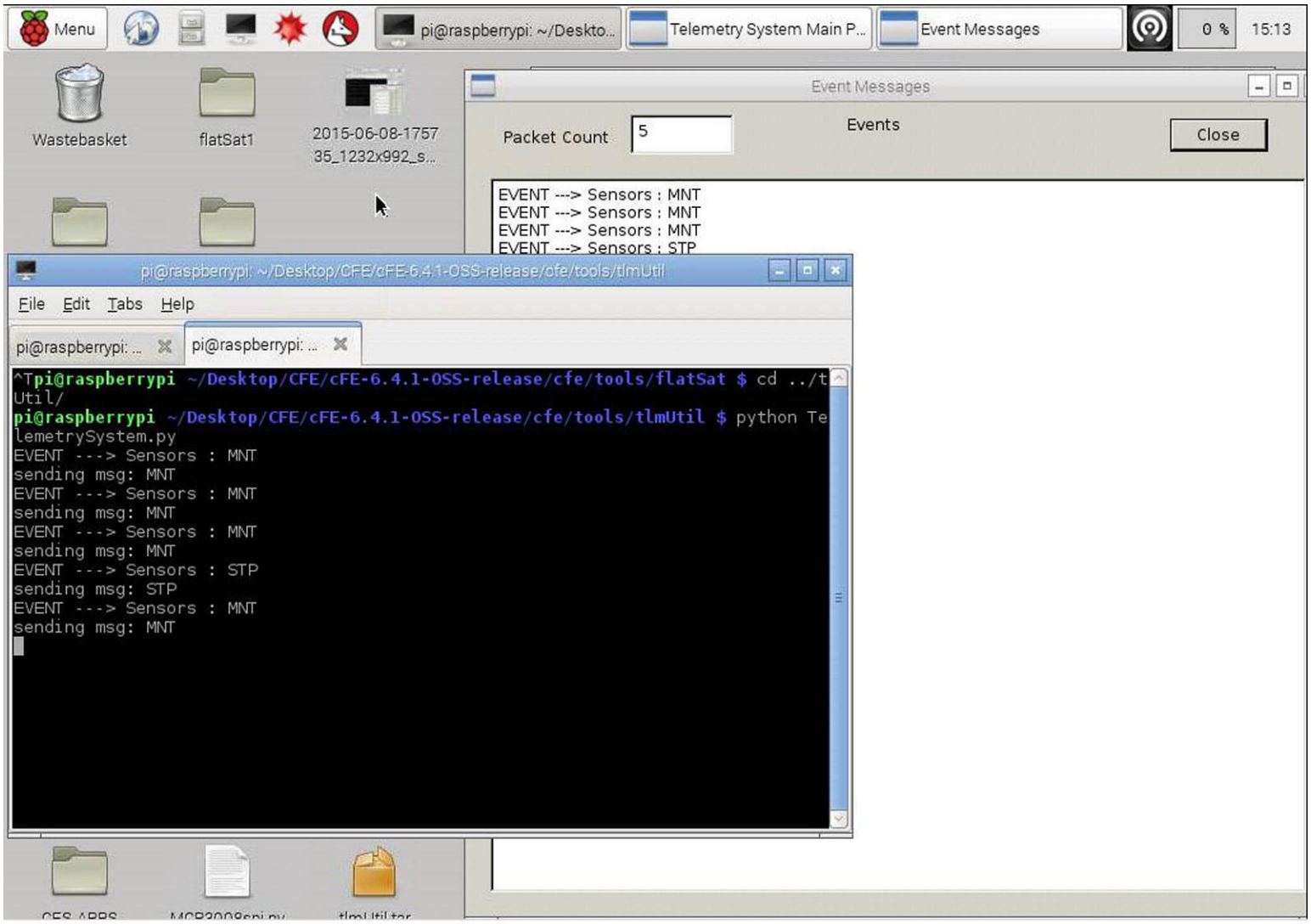
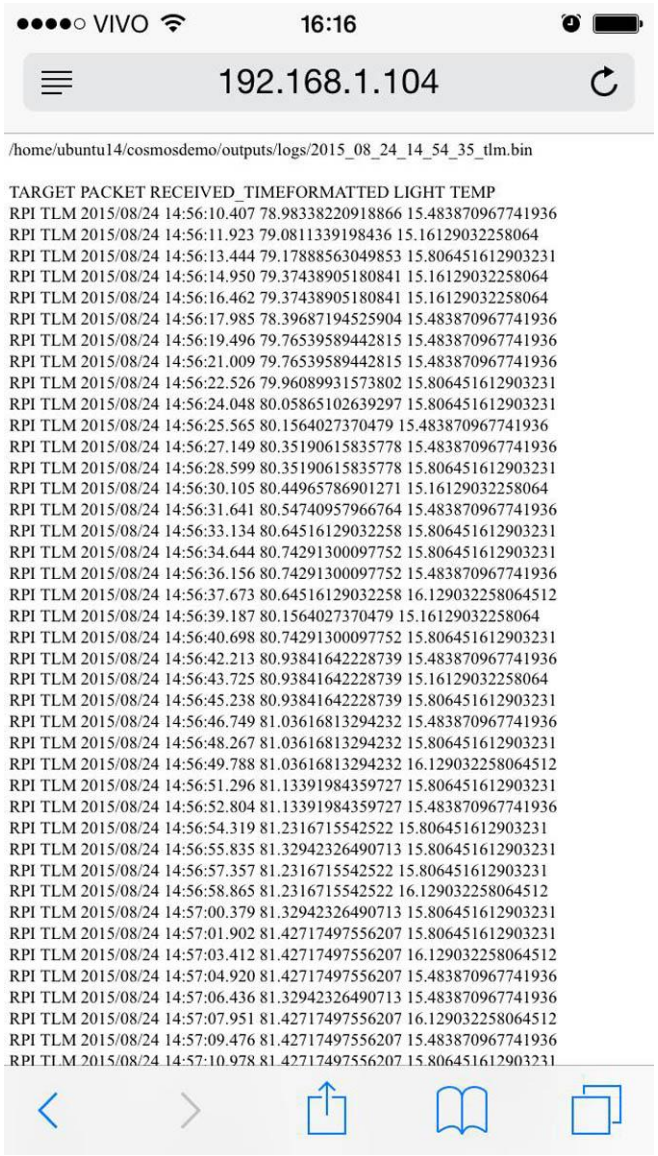

Telemetry Extractor
3:04 PM
Launcher
Telemetry Extractor
Configuration
Configuration File: o/config/tools/tlm_extractor/tlm_extractorFLATSAT.txt
ITEM RPI TLM RECEIVED_TIMEFORMATTED
ITEM RPI TLM LIGHT
ITEM RPI TLM TEMP
Add Item
Target: COSMO
Packet: LIMITS_
Item: ITEM
Add Item
Column Name:
Text:
Downsample Seconds: 0.0
File Selection
Log Files:
Browse...
Remove
/home/ubuntu14/cosmosdemo/outputs/logs/2015_08_24_14_54_35_tlm.bin
Output File: /home/ubuntu14/cosmosdemo/outputs/handbooks/flatsat_tlm.txt
Select
Time Period Start: N/A
Clear
Select
Time Period End: N/A
Clear
Select
Packet Log Reader: Cosmos::PacketLogReader
Select
Process Files
Open in Text Editor
Log File Progress
Overall Progress:
100%
Step Progress:
100%
Processing File 1/1: 2015_08_24_14_54_35_tlm.bin
Runtime: 0.909211596 s
HTML generated!
Done
Cancel
Command and Telemetry Server
Command Sender
Packet Viewer
Utilities
Telemetry Extractor
Choose What I Share


Menu
pi@raspberrypi: ~/Deskto...
Telemetry System Main P...
Event Messages
0 %
15:13
Wastebasket
flatSat1
2015-06-08-175735_1232x992_s...
Event Messages
Packet Count
5
Events
Close
EVENT ---> Sensors : MNT
EVENT ---> Sensors : MNT
EVENT ---> Sensors : MNT
EVENT ---> Sensors : STP
pi@raspberrypi: ~/Desktop/CFE/cFE-6.4.1-OSS-release/cfe/tools/tlmUtil
File Edit Tabs Help
pi@raspberrypi: ...
pi@raspberrypi: ...
^Tpi@raspberrypi ~/Desktop/CFE/cFE-6.4.1-OSS-release/cfe/tools/flatSat $ cd ../tUtil/
pi@raspberrypi ~/Desktop/CFE/cFE-6.4.1-OSS-release/cfe/tools/tlmUtil $ python TelemetrySystem.py
EVENT ---> Sensors : MNT
sending msg: MNT
EVENT ---> Sensors : MNT
sending msg: MNT
EVENT ---> Sensors : MNT
sending msg: MNT
EVENT ---> Sensors : STP
sending msg: STP
EVENT ---> Sensors : MNT
sending msg: MNT
CFS_APPS
MCP3008spi.py
tlmUtil.tar


●●●●○ VIVO
16:16
192.168.1.104
/home/ubuntu14/cosmosdemo/outputs/logs/2015_08_24_14_54_35_tlm.bin
TARGET PACKET RECEIVED_TIMEFORMATTED LIGHT TEMP
RPI TLM 2015/08/24 14:56:10.407 78.98338220918866 15.483870967741936
RPI TLM 2015/08/24 14:56:11.923 79.0811339198436 15.16129032258064
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RPI TLM 2015/08/24 14:56:40.698 80.74291300097752 15.806451612903231
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RPI TLM 2015/08/24 14:56:48.267 81.03616813294232 15.806451612903231
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RPI TLM 2015/08/24 14:56:51.296 81.13391984359727 15.806451612903231
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RPI TLM 2015/08/24 14:57:00.379 81.32942326490713 15.806451612903231
RPI TLM 2015/08/24 14:57:01.902 81.42717497556207 15.806451612903231
RPI TLM 2015/08/24 14:57:03.412 81.42717497556207 16.129032258064512
RPI TLM 2015/08/24 14:57:04.920 81.42717497556207 15.483870967741936
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RPI TLM 2015/08/24 14:57:07.951 81.42717497556207 16.129032258064512
RPI TLM 2015/08/24 14:57:09.476 81.42717497556207 15.483870967741936
RPI TLM 2015/08/24 14:57:10.978 81.42717497556207 15.806451612903231

TrapSat

- CapTechU Cubesat Project, awarded a NASA launch slot in 2018.
- Images and returns data on very small (mm) particles of space debris using an Aerogel capture mechanism and a camera.
- Flown multiple times to near-space on a balloon to prove concept, with very positive results.

Feed forward to Trapsat

- Use COSMOS for the control center function.
- Use the image processing pipeline in the Raspberry Pi for onboard processing of data. (Cubesats have very limited downlink)
- Energy cost of image processing trade.
- Monitoring for radiation damage
  - Active current monitoring and trending.
  - Functional Self-checks.
  - Heartbeat.
  - Ability to reset.

Next

- Secure commanding ap for user device. (no hacking our satellite!)
- Load test. How many “targets” can a server host simultaneously? Required mips/target?
- Implement cFS for (32-bit) Arduino as a Cubesat onboard computer code. May fly Arduino/Pi cross-checking pair.
- Expand on the use of COSMOS as a test environment for Cubesat-flatsats.
- Make the telemetry limits checker smarter. “Expert system.”
- Android ap version of COSMOS?
- What else?

References

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- TRAPSAT: https://www.captechu.edu/news-events/news-headlines/1819

- Contacts:

Patrick H. Stakem, phstakem@captechu.edu
pstakem1@jhu.edu
Guilherme Korol, guilhermekorol@hotmail.com
Gabriel Augusto Gomes, gabrielaugustodm@gmail.com