


An Appliance Based Approach to Small Satellite Command and Control

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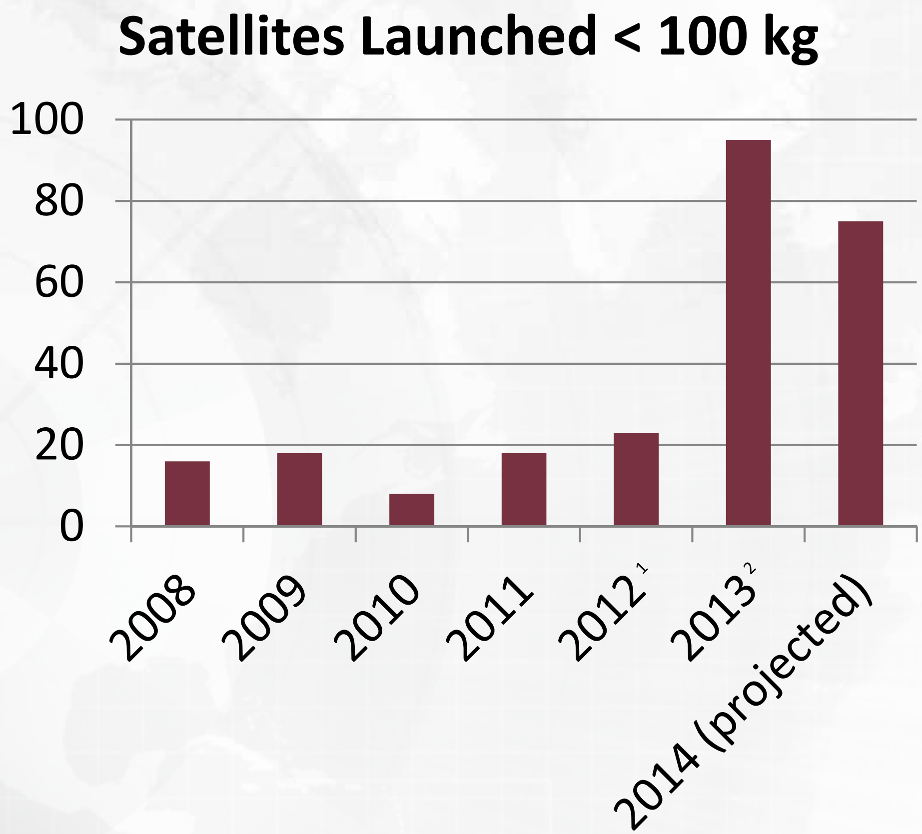
Small Satellite Command and Control
Background

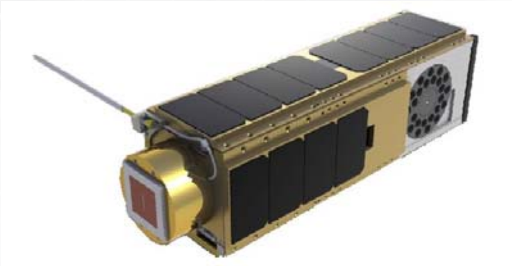


- 2013 Highlights:
  - 28 CubeSats + STPSat-3 launched November 20th, 2013 on a Minotaur I
  - 32 Small Satellites launched November 21st, 2013 on a Dnepr
- 2014 Manifest:
  - Planet Labs - 28 CubeSats[3]
  - ORS-4 - 13 CubeSats and HiakaSat[4]
  - NASA's Educational Launch of Nano-satellites (ELaNa) - 18 CubeSats[5]
  - Spaceflight Services Launch Manifest – 15 Small Satellites[6]

[1]"Worldwide Mission Model: 2013-2032", Teal Group Corporation, 29th National Space Symposium, Colorado Springs, CO, April 8-11, 2013
[2]Jonathan's Space Report, Launch Log, http://planet4589.org/space/log/launchlog.txt
[3]http://www.newspacejournal.com/2013/11/26/with-two-more-satellites-in-orbit-planet-labs-prepares-a-flock-for-launch-next-month/
[4]Operationally Responsive Space-4 Fact Sheet, http://ors.csd.disa.mil/media/ORS-4-final-Aug-2012.pdf
[5]"Getting CubeSat Missions to Orbit Over the Next Decade," Garrett Skrobot, ELaNa Project Manager, 27th Annual AIAA/USU Conference on Small Satellites 2013
[6]http://spaceflightservices.com/manifest-schedule/

Small Satellite Command and Control
Motivation

- How much of a factor is Command and Control (C2) in the small satellite market? Are current C2 approaches for small satellites hindering the growth of the market?
  - Changes in the technical requirements for small satellite C2
    - Complex and expensive Mission Unique Software is not required
    - Support for space and ground hardware common to the small satellite community
  - Changes in the financial requirements for small satellite C2
    - Traditional C2 solutions carry price tags that can be more than the total cost of a small satellite
    - Traditional C2 solutions create a high Total Cost of Ownership



Photos Courtesy: NASA

Small Satellite Command and Control
Approaches

- Kratos wanted to examine and redefine the small satellite C2 market
- Examined several approaches to changes in the technical and financial requirements of small satellite C2
  - Small Sat Operations Center – build a small satellite operations center and offer operations as a service
    - Did not eliminate the biggest cost drivers of satellite operations – people
    - Only met the government and commercial market's needs but not those of the educational market
  - Software as a Service – hosted C2 software for small satellite operators
    - Provided a low up front cost but high total cost of ownership
    - Did not easily meet government customer requirements
  - Appliance – build a small satellite C2 product
    - Met the changing financial requirements of small satellite C2 by reducing both up front cost and total cost of ownership
    - Different versions with increasing capability could be offered for each market

Kratos pursued the appliance approach as the best solution to its small satellite C2 goals.

Small Satellite Command and Control
Goals

- Reduce Total Cost of Ownership
  - Develop an off the shelf product to minimize Non-Recurring Engineering and align with the price points of small satellites and CubeSats
- Reduce Risk
  - Deliver a pre-integrated set of software applications and toolsets to meet C2 software requirements without performing any new software development
- Accommodate a condensed mission timeline
  - Use industry standard interfaces to eliminate mission unique ground system development and interface to satellite and ground hardware right away
- Develop a Scalable Solution
  - The capacity to support additional small satellites within a single architecture without requiring new development each time a satellite is added
  - The ability to operate one, multiple, or many small satellites is a requirement for the commercial ventures fueling the growth behind the small satellite industry with business cases relying on constellations of small satellites

Typical Ground Segment Functions

RF Reception / Transmission Antenna	Frame or Packet Decommutation	Command Generation	Procedure Scripting	Memory Management
Antenna Pointing and Control	Point Context Check	Command Formatting	Display Building	Mission Data Processing
RF Up / Down Conversion	Engineering Unit Conversion	Command Authority Check	Real-Time User Interface	Automated Anomaly Processing
Modulate / Demodulate Signal (MODEM)	Measurand Limit Check and Alarming	Transmission and Tracking	Ops Automation	Flight Dynamics
Encryption / Decryption (optional per mission)	Point and Track File Generation	Verification	Plotting and Trending	External Interfaces
	Ground Device Monitor and Control	Logging and Messaging	Raw Telemetry and Processed File Retrieval	Payload and Bus Mission Planning

Functionality Legend

- Ground Hardware
- Telemetry
- Commanding
- Additional C2 Req’ts
- Mission Unique

Ground Segment Functions in a Small Satellite C2 Appliance

Unique to Space – Ground Data Path

- RF Reception / Transmission Antenna
- Antenna Pointing and Control
- RF Up / Down Conversion
- Modulate / Demodulate Signal (MODEM)
- Encryption / Decryption (optional per mission)

Small Satellite C2 Appliance

Frame or Packet Decommutation	Command Generation	Procedure Scripting
Point Context Check	Command Formatting	Display Building
Engineering Unit Conversion	Command Authority Check	Real-Time User Interface
Measurand Limit Check and Alarming	Transmission and Tracking	Ops Automation
Point and Track File Generation	Verification	Plotting and Trending
Ground Device Monitor and Control	Logging and Messaging	Raw Telemetry and Processed File Retrieval

Unique to Payload and Mission Users

- Memory Management
- Mission Data Processing
- Automated Anomaly Processing
- Flight Dynamics
- External Interfaces
- Payload and Bus Mission Planning

Functionality Legend

- Ground Hardware
- Telemetry
- Commanding
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CONOPS
Architecture Drivers

- All user interfaces are via a web browser
  - Fastest and easiest sharing of data
  - Caters to the user bases' familiarity with web browsers
- Accommodate differing Concepts of Operation (CONOPS)
  - Automated operations, "Lights Out" operations centers, geographical separation, traditional Satellite Operations Centers
- Command and Control appliance provides a "one stop shop" for telemetry viewing and analysis, commanding, procedure creation, automation, ground monitor and control, and database ingest
  - Requires a number of standardized interfaces, to include:
    - Telemetry and Command Database
    - Space to Ground Interface
    - Ground Hardware Interface

Industry Standard Interfaces

- The following industry standards were chosen to eliminate mission unique ground system development and enable the user to interface to satellite and ground hardware right away
  - XTCE – XML Telemetric and Command Exchange
    - Telemetry and command database ingest
    - Co-adopted by the Object Management Group (OMG) and Consultative Committee for Space Data Systems (CCSDS)
  - GEMS - Ground Equipment Monitoring Service
    - Ground monitor and control
    - Also an OMG standard
  - CCSDS link standards
  - AX.25 data link layer protocol
  - HTML5 – Hypertext Markup Language version 5
  - HTTP – Hypertext Transfer Protocol

Industry Standard Interfaces
Telemetry and Command Ingest

- The XML Telemetry and Command Exchange (XTCE) standard from the Object Management Group (OMG) was selected for satellite database ingest
  - XML is a very easy language to code, debug, and understand
  - The XTCE standard capitalizes on these attributes to define satellite databases
    - Multiple parameters can be defined to include telemetry frame locations, frame sizes, calibration coefficients, and limits and command locations, sizes, and arguments
    - XTCE allows telemetry to be defined within subsystems for notification and alerts
  - Database ingest and updates are simple
    - The operator performs an ingest of the XTCE file to generate an operational database that contains each command, telemetry, derived, and local/global parameter
    - When the database changes, a new XTCE file is ingested
- Using XTCE eliminates the labor needed to define/negotiate a custom space to ground ICD and ingest script
  - The XTCE standard is already defined by OMG and provides all of the capability required in a satellite telemetry and command database

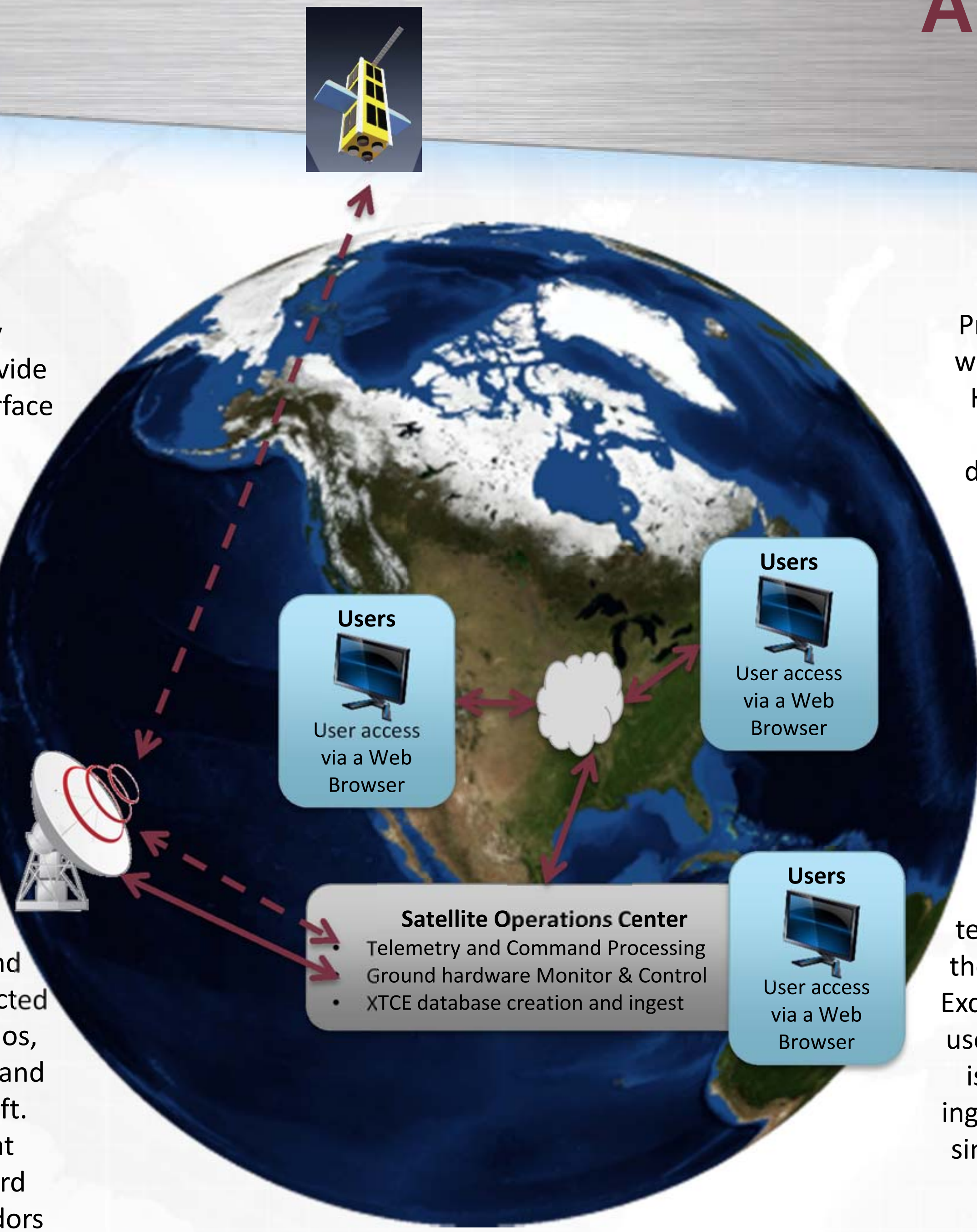
Industry Standard Interfaces
Ground Monitor and Control

- The Ground Equipment Monitoring Service (GEMS) standard, also from OMG, was selected to provide a capable interface for ingest to telemetry, sending commands, and controlling ground equipment
  - GEMS is focused on satellite ground system equipment Monitor and Control (M&C)
  - The interface works as an exchange for data, directives, and status values
- Appliance should allow numerous devices to be integrated
  - Define directives and status points in an XML file and ingest along with the XTCE database
  - Operators see the status of the integrated system of spacecraft and ground equipment monitoring all on the same page and are commanded/monitored the same way, and all can be uniformly automated
- Ground directives could also be included in automation procedures
  - Automating pre-pass ground hardware configuration and set up and post-pass ground hardware deconfiguration and clean up

Architecture

CCSDS command and telemetry interfaces are well defined and provide a straightforward approach for interface via predefined socket delivery.

Provide user interfaces via a web-based UI. Leveraging an HTML5 compliant product eliminates the need to download apps or plug-ins.



Appliance performs Monitor and Control (M&C) of network connected front end devices (modems, radios, antennas) that route commands and telemetry to/from the spacecraft. Utilizing the Ground Equipment Monitor Service (GEMS) standard promoted by OMG. Several vendors implement this standard.

Globe and CubeSat Courtesy: NASA

The spacecraft command and telemetry database is defined via the XML Telemetry and Command Exchange (XTCE) standard. The end user simply ensures their database is in that format for ingest. The ingest process could also produce a simple set of starter display pages and telemetry limit check procedures enabling faster integration.

Small Satellite C2 Cookbook

GRANDMA'S CHOCOLATE COOKIES

1 cup butter, softened
2 cups sugar
2 beaten eggs
4 squares melted unsweetened chocolate
1 tablespoon vanilla extract
2 cups sifted all-purpose flour
pinch of salt
finely chopped walnuts

Cream butter thoroughly. Add sugar, one cup
Add eggs, melted chocolate, vanilla, salt and f

Chill dough for about 30 minutes. Form into 1"
cookie sheet. Flatten with a fork dipped in sug
chopped walnuts on top. Bake at 350° for 8 to

SMALL SATELLITE GROUND SYSTEM

1 Small Satellite Appliance (preferably quantumCMD)
1 RF Subsystem
2 xml files

Plug appliance into network and power up.
Connect via web-browser.
Ingest XTCE database.
Ingest xml file for RF Subsystem M&C.
Configure telemetry screens and procedures to operators taste.

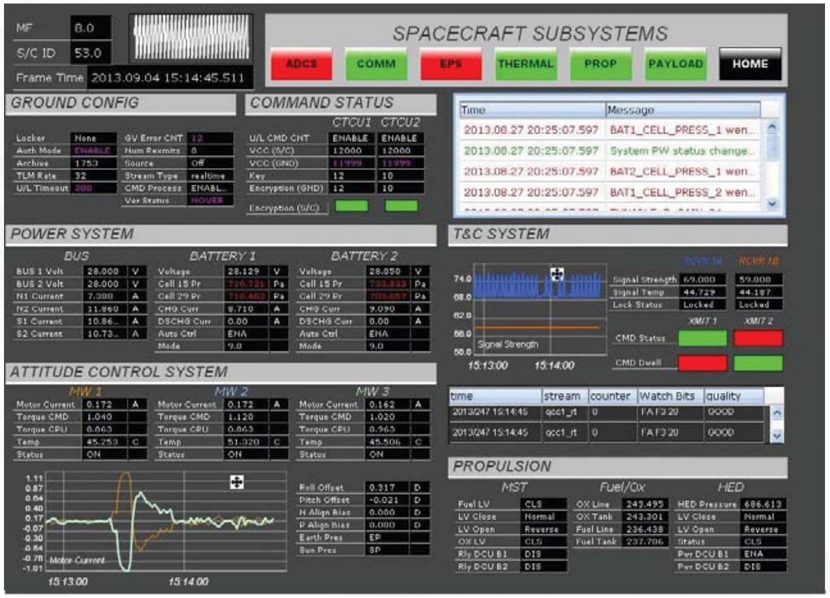
Fly mission.

Kratos quantumCMD

- Kratos has worked on developing a small sat C2 appliance for the past year under an IR&D effort
  - Goal – Follow the Recipe
- Focused on Reducing the Total Cost Ownership, reducing risk, and accommodating a condensed mission timeline through the use of industry standard interfaces, pre-integrated software applications, and focusing on the core C2 requirements

quantumCMD

- ✓ **Meets C2 requirements out-of-the-box**
- ✓ **Ingests satellite databases using standard XTCE format**
- ✓ **Robust automation reduces operations costs and the risk of operator error**
- ✓ **HTML5 web-based user interface**
- ✓ **Modular to meet growing mission needs**
- ✓ **Reduces the risk imposed by software development while also reducing cost**



quantumCMD development has followed the recipe – Kratos is now looking for validation in how the market adopts the idea

Small Satellite Command and Control
Conclusion

- Small satellites are the new reality in space missions
- Small satellite C2 architecture is driven by mission needs:
  - Reduced cost → meeting small satellite economics
  - Minimal Technical Risk → allowing innovation in other mission areas
  - Compressed schedules → supporting rapid and responsive launch initiatives
  - Scalability → C2 of one or many small satellites
- The correct solution to solve this problem:
  - Focuses on the core command and control requirements
  - Uses industry standard interfaces
  - Is available at a competitive price point for smaller missions

A promising approach to supporting smallsat C2, a turnkey appliance may align C2 solutions with the smallsat revolution