Transforming Space Missions Into Service Oriented Architectures

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Vision: Sensor Web Enablement via a Service Oriented Architecture (SOA)

- Abstract data from process of obtaining data via services above
- Access sensors and data via Internet and use services similarly to how “Google Earth” is used
- User chains multiple services from various sensors and data service providers together as needed
- Built on top of GMSEC and cFE
Service Example

- User discovers service on Internet with search tools
- User picks desired service, pays and doesn't get involved in details of how service is provided
- New services can be easily plugged in and removed thus circumventing risk of obsolescence
- Fault tolerant because user can locate and connect to alternative service

SPS Example: Discovering and Tasking
EO-1 Sensors (OGC OWS-4 Demo)

- Wrap EO-1 satellite in SensorML and publish its capabilities
- Enable generic command tasking request via SPS
- Enable generic alert services via SAS

Front end of service
"Generic request"

Back end "plug-in" to fulfill service

Web Catalog Services
- Store capabilities
- Process user query and return the result

EO-1 Tasking Webserver
- Accept user goal requests
- Automatically sort by priority
- Perform auto-sync with onboard planner, CASPER

EO-1 Tasking Map

Sensor Planning Service (SPS)

SensorML Wrapper

EO-1

STS
S/C ABC

SAS
SPS
SOS
Future Expansion

Internet

Service Aggregator

Deliver Package (DP)

UPS
FedEx
Airborne

Next Day $14.95
2 Day $7.95
Slow boat to China $1.25
Validated new "back-end" predictive models which predicted problems for selected subsystems (SSR, RF Link, Power) and then autonomously initiated corrective actions through planning system before problem occurred.

- Unique innovation—Models self-update over time using real-time telemetry (e.g. as solar array degrades, charge current for battery changes over time, therefore model of state of battery has to change)
- Used GSFC Mission Services Evolution Center (GMSEC) message bus to enable communications between support components
Example of Service Chain to Fulfill Science Data Processing Needs

- Sensor Planning Services (SPS)
- Sensor Alert Services (SAS)
- Sensor Registry Services (SRS)
- Sensor Observation Services (SOS)
- Work Flow Chaining Services (WFCS)—e.g., BPEL
- Web Map Services (WMS)
- Web Feature Services (WFS)
- Web Coverage Service (WCS)

Advantages of SOA for Space Sensors

- Networked standardized interface connections, loosely coupled
  - Components connected at run-time
  - Enables discovery of services
  - Hides details of how service performed (encapsulated implementation)
  - Fault tolerant
    - Since connection occurs at run-time, if service not available, a component can find or “discover” an alternative service and if unavailable, can connect to another instance of the service if available
    - Troubleshooting is easier because information is provided at component and services level
  - Highly reusable
    - Standardized, networked “plug and play” interfaces
  - Scalable
    - Interactions between services and clients independent of location and numbers
  - Sustaining engineering for constellation simplified
    - Can initiate new instance of service or alternative service and then disconnect old services

Taken from: Hartman, Hoebel, *Lightweight Service Architectures for Space Missions*, SMC-IT 2006, Pasadena, CA
Key Differences

- Scenes and ground contacts are selected automatically based on scene priorities
- World Wide Web interface for requesting and acquiring observations
- High-level scene and contact “goals” are uploaded to the spacecraft instead of detailed command sequences
- Execution sequence can be automatically changed on-board
- Priority observations can be requested and acquired within hours
- Science data is immediately available for analysis on-board compared to days or weeks

Various EO-1 Sensor Web Experiments Conducted

Triggers  Onboard & Ground Tools  Uses

Volcano TIR dataset, Kilauea, Hawaii
EO-1 responds to triggers and has onboard triggers for land, thermal and clouds.

MOD08/Terra and Aqua used to detect hot spots for fires, volcanoes.
OSO, used for frost detection.

Communication Infrastructure: Cellular band architecture for spacecraft using phased array antennas (RFLO, GRC, Ge Tech, Univ of Colorado).

Ground:
- MOPS: Mission Operations Planning and Scheduling System (ISFC)
- SGC: Science Goal Monitor (ISFC)
- ASPEN: Planning & scheduling (JPL)
- EPISC: Earth Phenomena Observing System - Cloud screening

On-board:
- ASE: Autonomous ScienceCraft Experiment (JPL)
- LIDAR (Aerospace) - Onboard diagnostics tool

Fires:
- Rehabilitation
- Fuel map to predict fire spread
- Volcano eruption detection & assessment
- Flood assessment
- Ice breakup change detection
- Cloud screening
In this image, burned areas appear red while the unburned areas appear green. The blue burn perimeter vector is based on ground data.

Example of Rapid Delivery of Information for Decisions for EO-1 Sensor Web with WfCS

On 11-2-03, the NASA Wildfire SensorWeb was employed to collect data on the burn scars resulting from the Sini Valley, Val Verde and Piri fires in Southern California. MODIS active fire detections for the duration of the event were used to target an acquisition by the ALI and Hyperion instruments onboard EO-1. Such data are employed by the USDA Forest Service for Burned Area Emergency Rehabilitation mapping. BAER maps are used to target high risk areas for erosion control treatments.
Science Event Manager
Processes alerts and
prioritizes response observations.

EO-1 Flight Dynamics
Tracks, orbit, overflights, momentum management.

ASPEN
Schedules observations on EO-1.

Beginning to Implement Standards

- GSFC Mission Systems Evolution Center (GMSEC)
- Core Flight Executive (cFE)
- Core Flight System (CFS)
- SensorML
- OGC Sensor Web Enablement (SWE) standards

Integrated Services
Create, Integrate, Deploy, Manage

Application Services
SensorML Archives, Event Processing, Others TBD

Interoperability and Meta-Language Services
SensorML, IRC, Others TBD

GMSEC For Ground
Distributed Multi-Protocol Message Bus

cFE For Space
GMSEC Extended to S/C Bus--Onboard Integrated Message Bus Demonstration (December 2005)

Ground System Testbed

<table>
<thead>
<tr>
<th>ASIST Primary</th>
<th>DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMSEC Bus</td>
<td></td>
</tr>
<tr>
<td>ASIST Secondary</td>
<td></td>
</tr>
</tbody>
</table>

Core Flight Executive (cFE) on CHIPS

<table>
<thead>
<tr>
<th>Command Ingest</th>
<th>Telemetry Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>cFE Bus</td>
<td>Livingstone Adaptor</td>
</tr>
</tbody>
</table>

DC – Data Center
ASIST – Advanced Spacecraft Integration and System Test

Moving ST5 Models Onboard CHIPS Satellite Under cFS to Demonstrate Mobile Agents

- Mobile agent - autonomous software module that can easily be moved around a network
- Models transformed into mobile agents
  - Worked with Solid State Recorder agent (model) first
- Adapter built to make compatible with both GMSEC and Core Flight Executive (cFE)
- Demonstrated capability to move software running on GMSEC onboard to run under cFE
- Demonstrates beginning step to transform missions from central control to distributed control via self-managing software

ST-5 Constellation

GMSEC Apps

ASIST

DC

CHIPS Satellite with cFE Bus Onboard

Power Model Agent

Adapter

Adapter

via Berkeley & Wallops Ground Stations (UDP)

via DSN & McMurdo Ground Stations

GMSEC Bus

Fairmont, WV

via TCP/IP

DC – Data Center
ASIST – Advanced Spacecraft Integration and System Test

ST-5 – Space Technology 5

CHIPS – Cosmic Hot Interstellar Plasma Spectrometer
Extended Efforts

- GMSEC to used on SDO, GLAST, LRO
- GMSEC providing framework for C3I work in the Constellation Program
  - Will be used for ground and constellation of laboratories
- Two recent follow-on 3 year awards from AIST ESTO call for proposal to extend ST5 efforts
  - An Inter-operable Sensor Architecture to Facilitate Sensor Webs in Pursuit of GEOSS
    - Key topic – Interoperability and demonstration of service oriented architecture for space missions and sensor webs
    - PI: Dan Mandl - 3 year effort
  - Using Intelligent Agents to Form a Sensor Web for Autonomous Mission Operations
    - Key topic distributed mission control
    - Extend effort depicted on slide 16 in which ST-5 components turned into mobile agents for use onboard spacecrafts with GMSEC/CFS
    - PI: Ken Witt/ISR Co-I Dan Mandl/GSFC – 3 year effort

Extended Efforts

- Goddard Institute for Systems, Software and Technology Research (GISSTR) contract effort being applied to extend ST5 effort by Institute of Scientific Research (ISR)
  - Building GMSEC compliance tester for new components
  - Help to synergize other ESTO awards with above mentioned awards
  - Integrate ROME in collaboration with Capitol College into TRMM, GLAST and MMS
- West Virginia Challenge Grant (set-aside) to be applied to develop Sensor Modeling Language (SensorML) schemas for follow-on SOA efforts
  - SensorML schemas will describe sensor capabilities and once put in online registries, will enable discovering of those capabilities on the Internet
  - 200 member organization of OGC
  - 40 organization participating in OWS-4
  - Sensor Planning Service (SPS) one of key services being demonstrated with EO-1
Acknowledgements

- Additional info at: eo1.gsfc.nasa.gov
- and ase.jpl.nasa.gov
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Acronyms

- ASE – Autonomous Sciencecraft Experiment
- ASIST – Advanced Spacecraft Integration and System Testing
- ASPEN – Automated Scheduling Planning Environment
- CASPER – Continuous Activity Scheduling Planning Execution and Replanning
- CMS – Command Management Systems
- MOPSS – Mission Operations Planning and Scheduling Systems
- SCL - Spacecraft Command Language
Backup

Underlying "Plug and Play" Message Bus Architecture—Goddard Mission Services Evolution Center (GMSEC)

GMSEC architecture provides a scalable and extensible ground and flight system approach
- Standardized messages formats
- Plug-and-play components
- Publish/Subscribe protocol
- Platform transparency
- ST5 first mission to be totally GMSEC compliant

More info at: http://gmsec.gsfc.nasa.gov
cFE provides a framework that simplifies the development and integration of applications:

- Layered Architecture – software of a layer can be changed without affecting the software of other layers.
- Components communicate over a standard message-oriented software bus, therefore eliminating the need to know the details of the lower layers of inter-networking.
- Software components can be developed and reused from mission to mission.
- Developed by Flight SW Branch at GSFC.
- To be used on LRO.

Example of Rapid Mission Configuration Using GMSEC Interoperable Catalog Components:

GMSEC approach gives users choices for the components in their system. The TRMM mission rapidly selected key components from the GMSEC catalog.