Plug-and-Play for Creating “Instant” GN&C Solutions

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Responsive Space

- Spacecraft developed in direct support of responsive missions
  - Spacecraft need to be **built to inventory**
  - Constructed from **off-the-shelf components** based on varying mission needs, and/or
  - **Integrated rapidly** with payloads as they are identified and available.
- **Microcosm’s Vision:** Provide information to the end user **within 24 hours** of an identified need
  - **Low Cost** — Total mission cost < $20 million/spacecraft
    - Includes launch, spacecraft, payload, and mission ops
    - Allows systems to be built to inventory
  - **Short Duration** — Less than 6 months planned mission life
    - Reasonable to launch in response to tactical needs
  - **Small Spacecraft** — Total mass < 1000 lbs, possibly < 500 lbs
    - Reduces both launch and mission cost
  - **Single Function** — 1, or at most 2, payloads per spacecraft
    - Allows matching response to the identified need
Spacecraft “Built to Inventory”

Off-the-Shelf Spacecraft Bus mated with payload

Off-the-Shelf components “plugged” into bus structure

Off-the-Shelf subsystems, Integrated to create spacecraft bus

Off-the-Shelf software, flexible and robust, tested and ready for use
Creating an Instant GN&C System

• General Philosophy: Abstract the core software components from the specific sensor and actuator suite(s), by establishing *standard data elements and descriptors*
  – Remove traditional subsystem component boundaries
  – Define interfaces in terms that remove vehicle specific information (components model/serial number and mass properties)

• Provide vehicle specific information during operations via configuration files

• Implementation will include significant innovation
  – Generic software components can be thoroughly tested and re-used (off-the-shelf) much like hardware components for rapid response

**GN&C Architecture is *data centric***
Data Centric Information

Rotation:
- Angle (3)
- Rate (3)
- Acceleration (3)

Time:
- Establish Relative Position of Celestial Bodies and Associated Forces
- Establish Relative Order of Measurements

Third Body Angles:
- Earth (2)
- Earth Rate (2)
- Sun Angle (2)
- Moon Angle (2)
- Star Angle (2)

Translation:
- Position (2)
- Rate (3)
- Acceleration (3)
The goal of the original software development effort is to keep the GN&C core algorithms completely *generic and reusable*. This development approach is *antithetical* to traditional AODCS software development approaches.

- NOT dependent on
  - the sensor suite
  - the actuator suite
  - specific vehicle characteristics

This development approach is *antithetical* to traditional AODCS software development approaches.
Generic Pointing Capability

**Sun Point** — orient a selected body vector toward the sun

**Ground Track** — orient a satellite body vector to follow a specific lat/long trajectory updated at each step.

**Ground Stare** — orient selected body vector toward a specific lat/long

**Inputs, Processing and Outputs are the SAME regardless of what is pointing where**

**One Law** — reduce error between sensed and desired state
A New Paradigm for GN&C Software

- A **Generic GN&C Core** that calculates required vehicle accelerations to meet desired state based on measurements/estimates
  - May not allow for optimization of the control system for each mission
  - Will facilitate re-use and rapid integration (Responsive Space)
  - Adaptive control laws accommodate varying sensors, actuators and mass properties

- Integrate sensors and actuators to meet specific mission requirements
  - High fidelity knowledge requirements will lead to selection of more expensive, higher accuracy sensor(s)
  - High fidelity control requirements will lead to selection of more complex actuator(s)

A Data Centric Architecture implies that specific devices and/or subsystems are not the system drivers – Identifying the “correct” vehicle configuration to meet the requirements is the new driver
Disruptive Technology

• Reusable “instant” GN&C software for spacecraft applications is a nascent technology
  – Modest performance
  – Moderate cost
  – Rapid development & integration niche applications

• As components and tools become available, extensions are developed to enable high performance, for a broad range of missions:
  – Costs will be significantly reduced
  – Schedules will be greatly compressed
Disruptive versus Sustaining Technologies

Source: CIO Magazine: www.cio.com/archive/040101/disruption.html, and Clayton Christensen’s “The Innovator’s Dilemma,”
Balancing Performance With Cost

- Performance of the PnP, reusable GN&C system is based on identifying the correct sensor and actuator configuration
  - Balance the specific mission need with necessary components
  - Balance components and associated costs/schedule constraints with mission needs
Sensor and Actuator Selection Drive Performance

- Precision: - Precision Wheels & Models
  - Adaptive Dynamic Models

- Agile: - CMGs
  - Quality Dynamic Models

- 3-Axis: - Thrusters
  - Wheels
  - Quality Dynamic Models
  - Torquers (Momentum Unloading)

- Spin: - Thrusters
  - Torquer
  - Basic Dynamic Model

- Passive: - Gravity Gradient

- None

- Advanced: - Star Tracker
  - IMU
  - GPS

- Moderate: - Sun Sensors
  - Magnetometer
  - Earth Sensor

- None

- Precision: - Precision Star Tracker
  - INS Class IMU
  - GPS

- None

- Cost

- Accuracy

- Cost

- Accuracy
On-Board Components vs Performance

Knowledge

- Baseline Plus:
  - Star Tracker

Baseline:
- Sun Sensors
- Magnetometer
- GPS
- 1 Momentum Wheel (Pitch)
- 3 Magnetic Torquers

Baseline Plus:
- IMU
- 3 Wheels/CMG

Baseline Plus:
- IMU
- 3 Wheels/CMG
  (3 Axis Agility)

Control

- Baseline Plus:
  - 3 Wheels/CMG
  (3 Axis Agility)

- <1 arcmin
  - High Availability

- ~1 Degree
  - Moderate Availability

- ~1 Degree
  - Agile only in Pitch

- ~1 Degree
  - 3 Axis Agility

- <1 arcmin
  - 3 Axis Agility

Microcosm Inc

HRP Systems
PnP and GN&C Applications

• GN&C provides a particularly challenging test case for Re-Use
  – Mission criticality
  – Real-time operation / Low tolerance for latency
  – Very high availability and reliability requirements
  – Increasing bandwidth and computational requirements
  – Complexity
  – Coordination requirements

• Top-level requirements for implementing an architecture for Instant GN&C applications:
  – Real-time (predictive, if not deterministic) performance
  – Support high availability, capable of fault tolerance
  – Scalable and extensible design (to both varying levels of network bandwidth and higher capability processors)
  – Low hardware overhead — size, weight, power
  – Compact software (to maximize the use of low cost microcontrollers)
  – Leverage existing technology (hardware, software, protocols)
  – Simplify system design and integration process
  – Maximize reuse (through well defined services and APIs)
  – Maximize portability (through partitioning of platform dependent code)
GN&C Implementation Challenges

• Development of a generic, re-usable GN&C core is not an optimized implementation for each specific mission objective
• Risk can be mitigated through additional helper applications
  – Improve performance of GN&C Core through optimizing the quality of data inputs
  – Provide multiple combinations/permutations to establish “best estimate” knowledge
  – Use “upgraded” compliment of sensor/actuator suites to improve performance if needed to meet mission requirements
• Create a mechanism or framework for including all available sensed information at any given time
  – Non-homogeneous
  – Varying data rates
  – Intermittent data or data drop-outs
• Determine the best estimate of spacecraft position and attitude using multiple sources of information
  – Sensed or measured data
  – Synthesized or derived data
  – Analytical data measurement models that build from data if and when available
Roadmap to an Instant GN&C Solution

Plug & Play ADACS: Disruptive Technology
(Drastically Reduced Development, Integration and Testing Costs for Increasingly Challenging Missions)

Gen 1 PnP
- Mid-range Components
- Plug & Play Adapters
- Simple xTEDS

Gen 2 PnP
- High-end Components
- Integrated Plug & Play Complex xTEDS
  - Transfer fxns
  - Instantaneous Error Covariances
  - Calibration

Gen 3 PnP
- Premium Components
- Integrated Plug & Play
- Adaptive xTEDS
  - Transfer fxns
  - Instantaneous Error Covariances
  - Calibration

Performance
- 0.0001° (0.36 arcsec)
- 0.001° (3.6 arcsec)
- 0.01° (36 arcsec)
- 0.1° (360 arcsec)
- 1° (3600 arcsec)

Experimental/Demonstration

Time
- Today
- 5 yrs
- 10 yrs
- 15 yrs

Optical

Communications
Achieving an Instant GN&C Solution

- Plug-and-Play (PnP) is both an enabling and an enhancing technology for creating an instant GN&C solution
  - Re-use is critical
  - Independence from sensor and actuator suite allows for rapid response and reduced integration times
  - State of the art GN&C techniques can still be applied

<table>
<thead>
<tr>
<th>Enabling Technology</th>
<th>Enhancing Technology</th>
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<tbody>
<tr>
<td>• Rapid Design/Integration/Test</td>
<td>• Applicable to Majority of Space Systems</td>
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<tr>
<td>– Configurable/Flexible ORS Spacecraft Designs</td>
<td>• Significant Reduction in GN&amp;C Cost and Schedule</td>
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<tr>
<td>– 6-Day Spacecraft</td>
<td>– Reduces Labor: Modeling, Simulation, Analysis, Testing</td>
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<tr>
<td>• Very Low-Cost Spacecraft</td>
<td>• Improved Fault Tolerance</td>
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<td>– Very Low ➔ ONRE</td>
<td>• Improved Flexibility and Upgradeability</td>
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<tr>
<td>– Very Low-Cost Design/ Integration &amp; Test</td>
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<td>– Configure-Assemble-Verify-Fly</td>
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Conclusions

• The performance achieved with a self-configuring systems may not be optimized for the particular vehicle configuration.

• The goal of an “instant” GN&C system is that the solution will be good enough.

• It is anticipated that re-usable GN&C software modules will be created and accepted in much the way hardware components are currently established:
  – They must be thoroughly tested
  – They will facilitate instant or self-configuration
  – Rapid Integration can be achieved

When good enough is added to the “instant” availability the new system is revolutionary in terms of providing an enabling capability that moves small satellites into the mainstream of the responsive space arena.