Spacecraft Plug-and-Play Architecture (SPA) Standards Applied to Guidance, Navigation, and Control (GN&C)

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Vocabulary / Terminology

- **SPA Application –** A SPA compliant software component
- **SPA Component –** A SPA compliant hardware device or software application
- **SPA Device –** A SPA compliant hardware component
- **SPA Gateway –** A uniquely addressable SPA core component used to bridge between two different SPA network spaces.
- **SPA Network –** An addressable and routable physically connected infrastructure composed of standard SPA transports for the purpose of transporting SPA messages between SPA endpoints and SPA gateways. The SPA network is made available as a SPA service to SPA components through a standard interface.
- **SPA Processor Resource –** A SPA device containing a processor that advertises itself via xTEDS as a discoverable, shared resource for executing SPA applications
- **SPA Services –** SPA-specific capabilities and functionality available to SPA components by SPA core components through a standard interface.
- **SPA System –** An integrated collection of interoperating SPA components
- **ASIM –** An Appliqué Sensor Interface Module (ASIM) is a small microcontroller circuit card that provides a logical and physical interface from a non SPA compliant device to the SPA network. The ASIM contains information about the device and its functions and translates between device's native command and data interface to the standard interface as defined in the xTEDS.
- **xTEDS –** An electronic data sheet used as the SPA component interface specification

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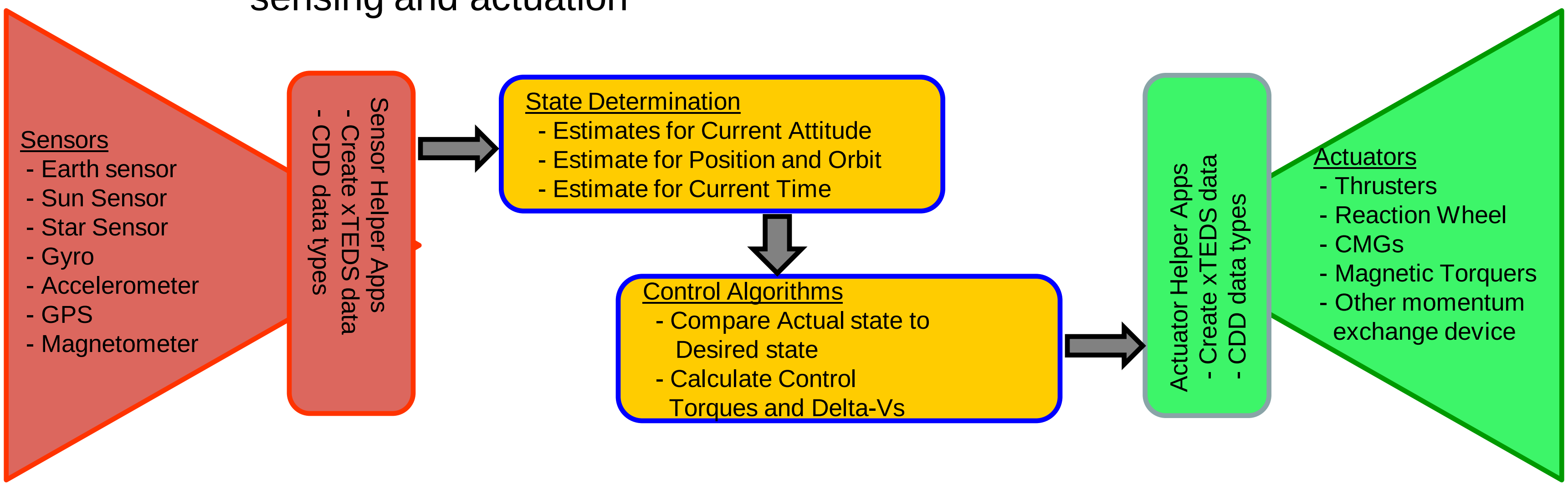
Spacecraft Plug-and-Play Architecture (SPA)

- SPA is a collection of standards designed to facilitate rapid assembly, integration, and testing (AI&T) of spacecraft systems using modular components.
  - American Institute of Aeronautics and Astronautics (AIAA) is working to create initial SPA standards for released in early 2011.
  - Open Standards providing methodology for creating self-organizing and self-describing components (hardware and software)
  - PnP Interface definition based on the OSI Model (Open System Interconnection Reference Model) which includes seven layers
- Hide complexity of the system with self-defining interfaces
  - Machine parsable interface definition
  - Machine negotiated integration
- Publish / Subscribe framework for acquiring data
  - Requires adherence to SPA Ontology and associated Common Data Dictionary (CDD)

Basic GN&C Elements

- Guidance, Navigation, and Control (GN&C) includes
  Sensor → Processing → Actuator
- Sensor and actuator data interface must be standard
  - Comply with CDD for data type
  - Include reference frame, performance, and lab usage attributes
- Processing is "generic"
  - Data elements can be provided to / from different SPA components
  - Varying levels of system performance resulting from varying sources of sensing and actuation



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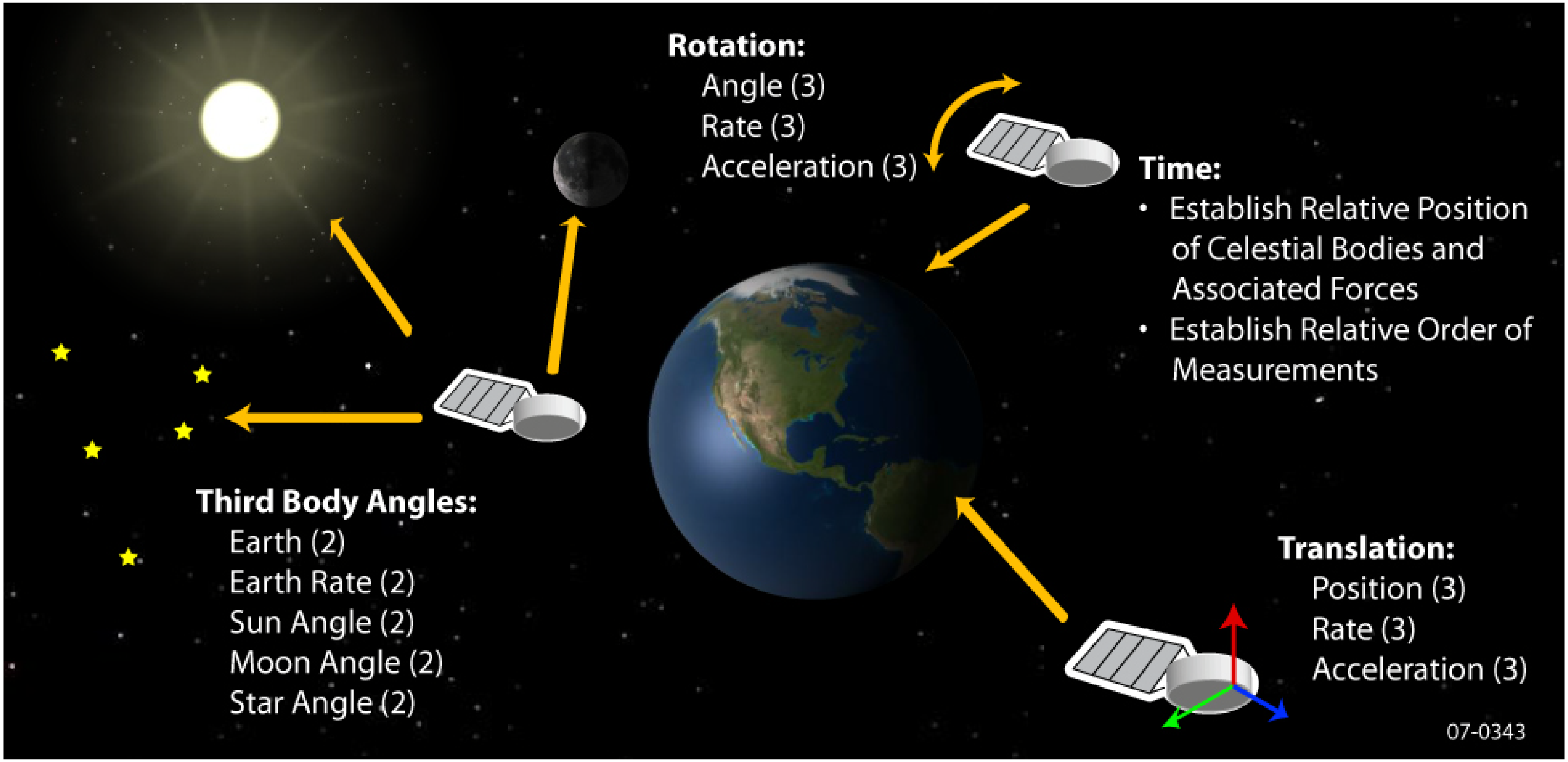
A New Paradigm for GN&C Software

- 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
- Select and 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

Data Centric Information



Data Centric implies that data is maintained in terms of "Physics" for complete reuse and transportability

Extensible Transducer Electronic Data Sheets (xTEDS)

- xTEDS should focus on varying levels of output to achieve scalable SPA components
- Multiple vendor products should be interchangeable based on pre-defined CSS and xTEDS
- Expose low level data via xTEDS for use in a different application than is traditionally expected
  - Remove traditional subsystem component boundaries allowing data to be used in new applications
- Expose top level data via xTEDS to allows for integration of 3 – 5 main application domains (power, ADC, C&DH, etc) with no necessary understanding of how solutions are achieved
  - Allow systems engineer to integrate and build a spacecraft with limited reliance on domain experts

A Data Centric Architecture *implies that xTEDS expose data a varying levels of fidelity and without reliance on specific vendor information – Allowing the user to build a system from low level pieces or from subsystems, as they desire.*

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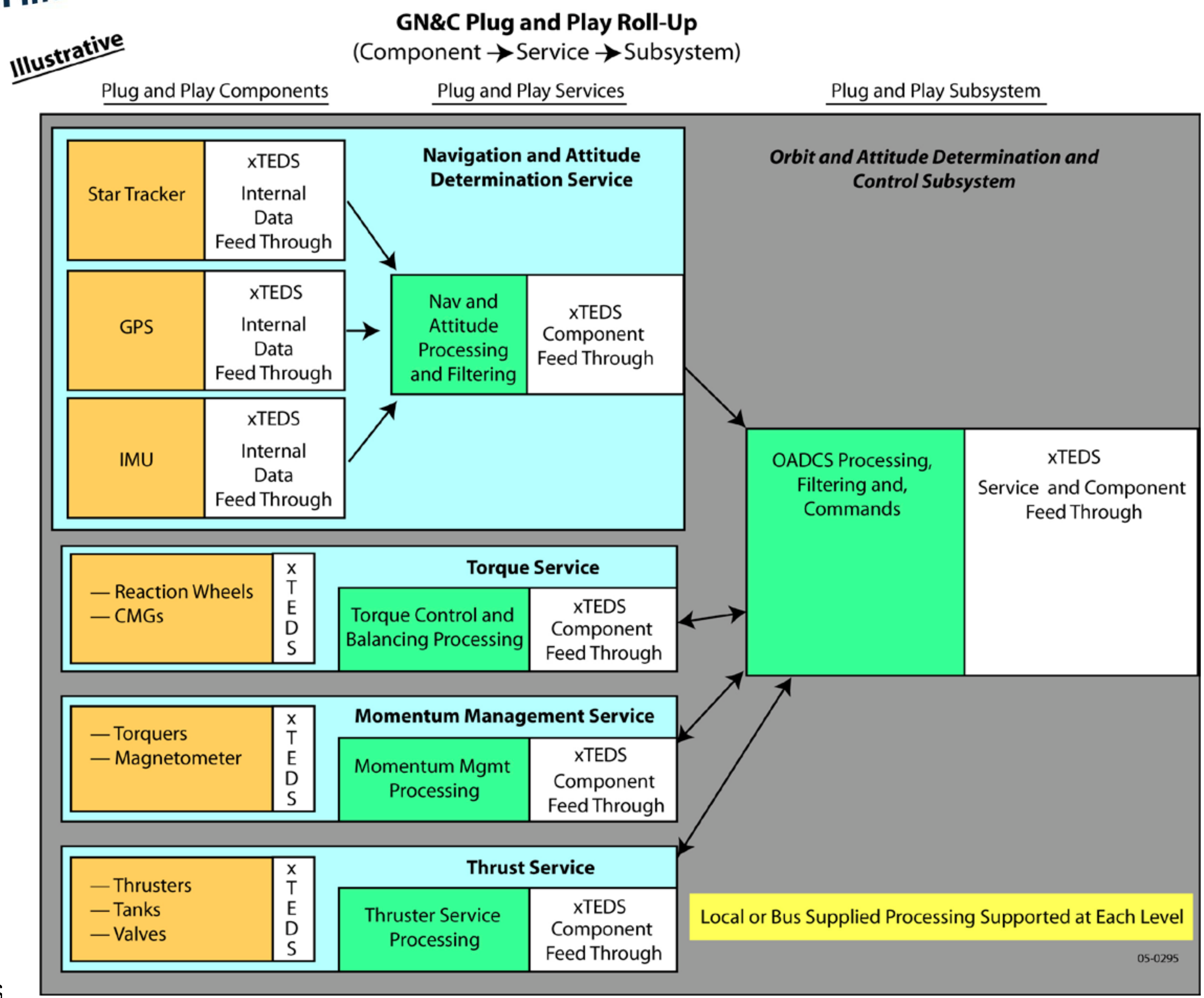
Hierarchy of GN&C Functionality



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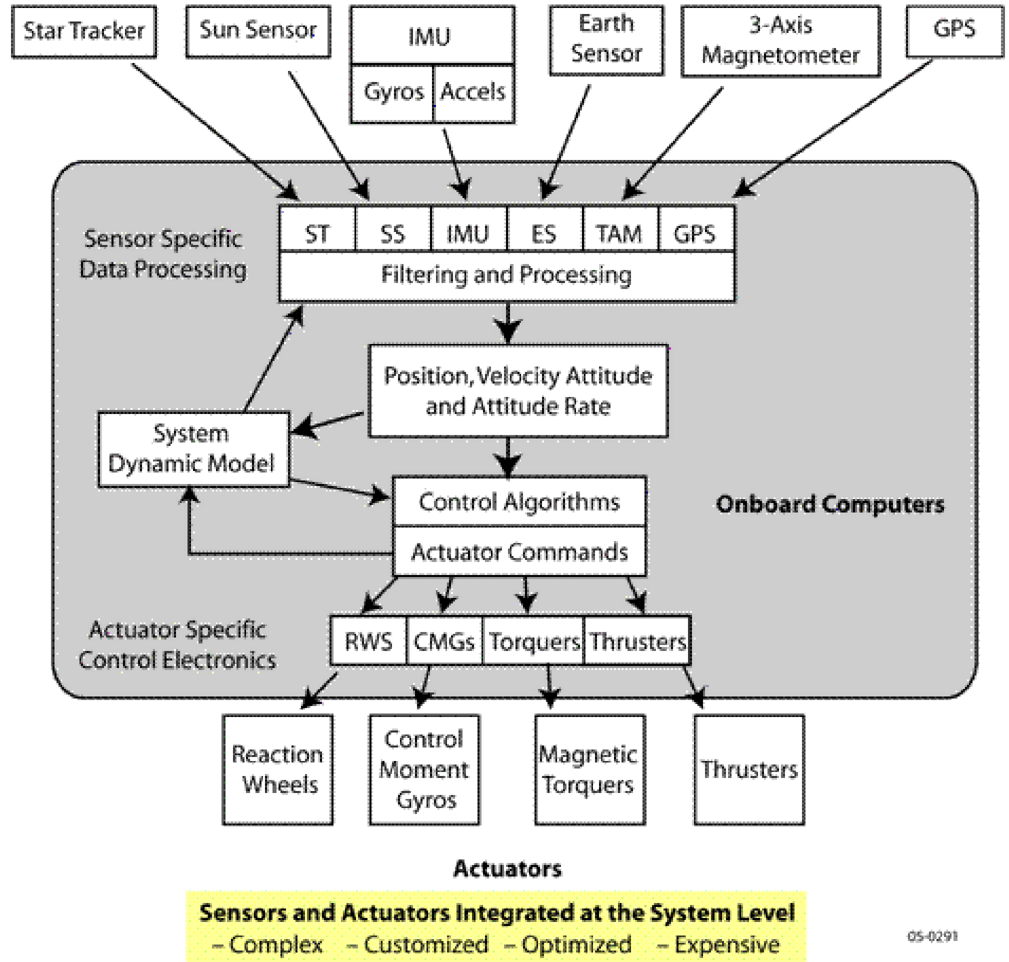
Traditional GN&C System

- Core software elements are often specialized and complex
- FSW elements typically reside in a general purpose on-board computer
- sensor and actuators are integrated at the system level which leads to customization and complexity



The traditional system is optimized for a specific mission, However, it is typically very expensive and slow to reach launch

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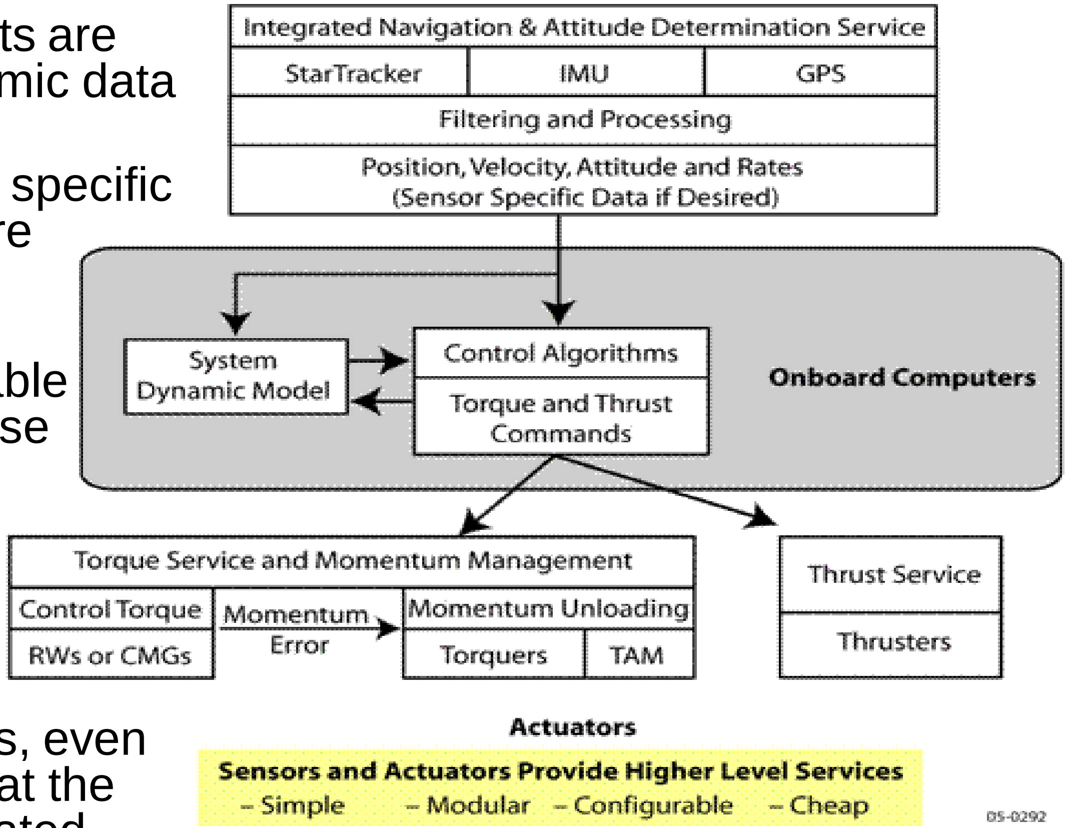
Hierarchical, Modular GN&C System

- Core processing components are more generic, based on atomic data elements
  - the sensor and actuator specific software components are pushed closer to the component itself
  - Flight software is re-usable in support of the response space paradigm
- Sensors software elements are modular and configurable, based on the specific mission
- Use of atomic data elements, even the filtering and processing at the sensor front end can be created and test a priori, then put into inventory for rapid assembly and test



The hierarchical and modular system is optimized for rapid integration and response

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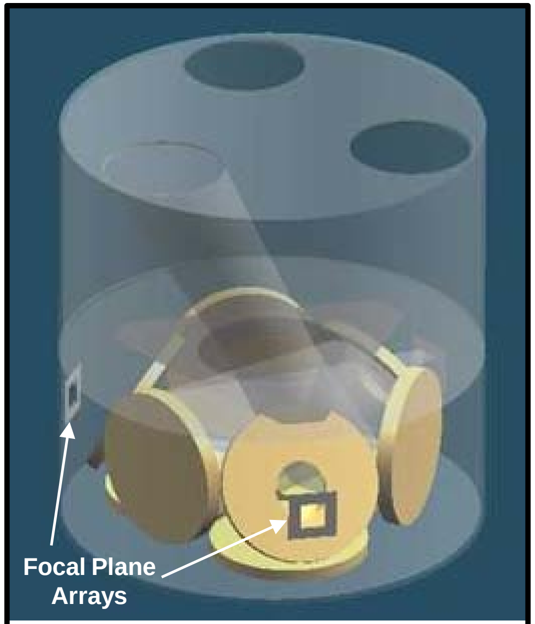
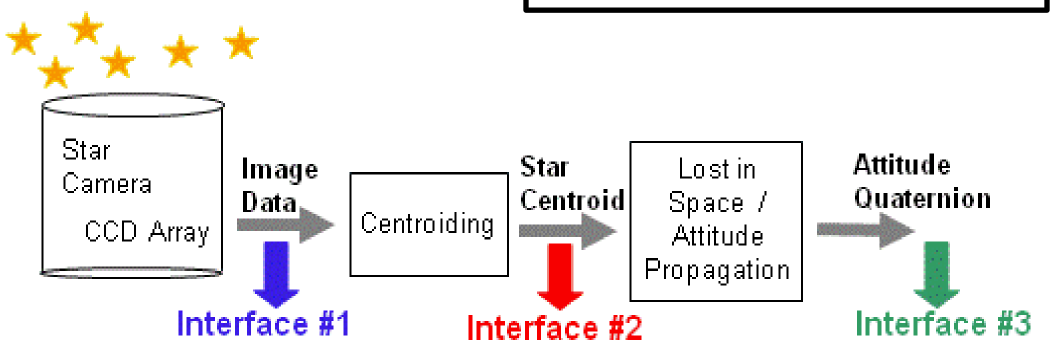
MicroMak PnP Star Sensor

- The MicroMak Star Sensor employs 3 simultaneously imaging independent telescopes with 4.5 degree fields-of-view (FoV)
  - Separated by 120 degrees
  - 30 degrees off of the sensor central axis
  - 3 separate focal plane arrays (FPA)
  - All reflective optics
- There are three potential output locations for MicroMak and each can have a standard RS-422 interface or convert to PnP SPA interfaces through memory mapping

Model of Expected Design for MicroMak Operational Sensor

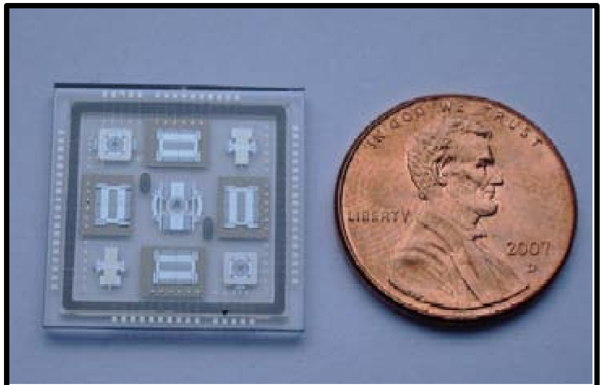


Sensor Geometry, Showing Light Path and All Optical Elements



PnP MEMS IMU

- PnP Micro-Electro-Mechanical (MEMS) Inertial Measurement Unit (IMU) is rooted in an instrument that has been developed by MilliSensor Systems and Actuators (MSSA)
  - Single die with 9 MEMS instruments – specifically: 3 gyros and 6 accelerometers
  - 6 degrees of freedom
  - Digital drive/read electronics
- Inertial Reference Unit developed for PnPSat-1 built around three single axis Analog Devices components (ADIS-16355)
  - ASIM provided by Data General and enclosure provided by SpaceWorks
  - ASIM was programmed for use with AFRL middleware (SDM)
  - ASIM also included “value added processing” in terms of a filter

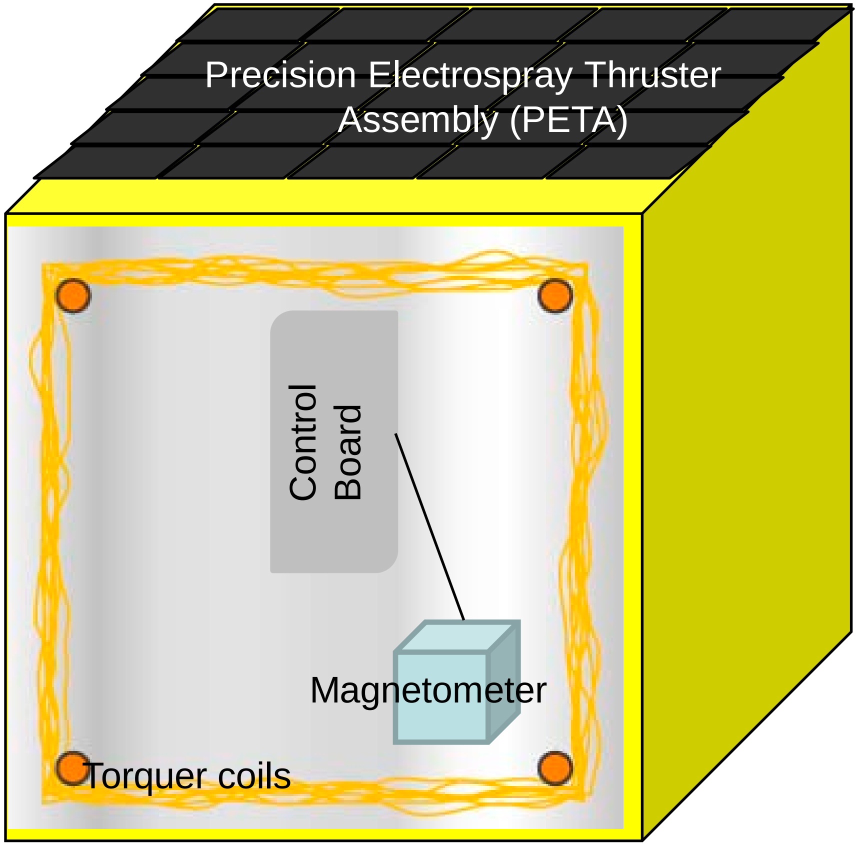


MilliSensor Systems and Actuators (MSSA) MEMS IMU Instrument

Basic IRU configured and Integrated into PnPSat-1

PnP CubeSat DeOrbit

- CubeSat DeOrbit can be standalone or make use of GN&C components available on a vehicle
  - SPA-I physical interface
  - xTEDS and CDD adherence
- PnP implementation allows DeOrbit to be tailored based on mission needs and available sensors from GN&C application
- DeOrbit can also supply additional PnP capabilities
  - Propulsion
  - Attitude control
  - Magnetic field measurements
  - Magnetic torque



Notional 1U CubeSat DeOrbit Implementation

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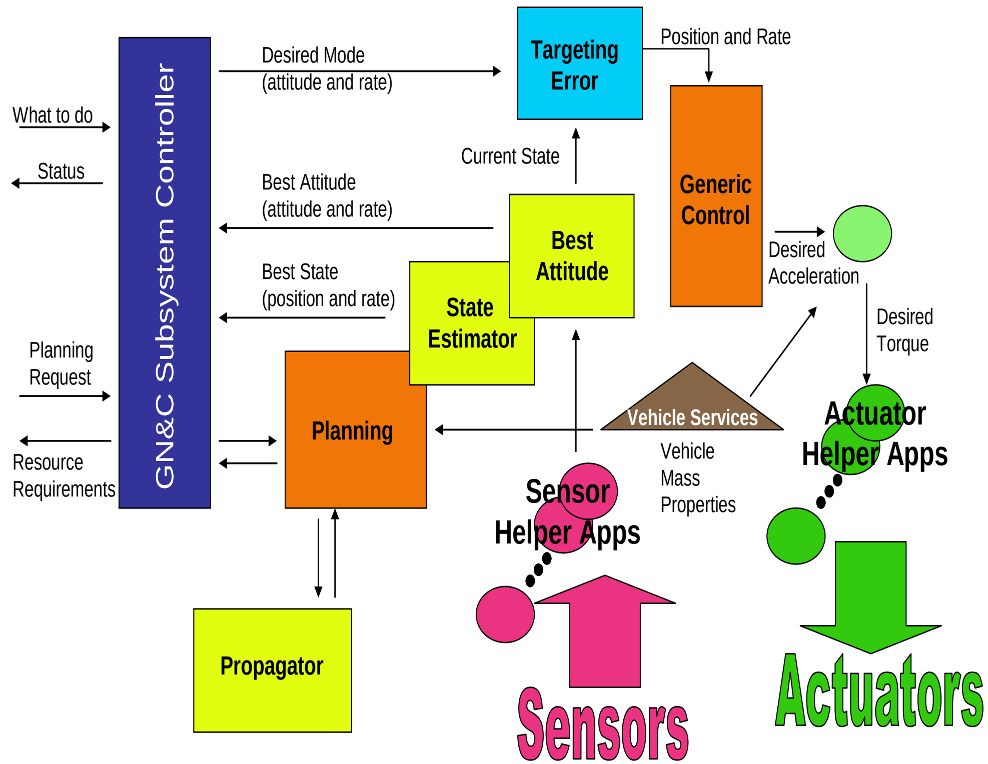
GN&C FSW Design

- Partitioning and architecting GN&C flight software (FSW) for reuse
  - Algorithms created generically, rather than for a specific sensor/actuator suites, to make use of run-time definition of sensors and actuators using atomic data nomenclature
  - Switching logic or rules used to integrate software with any sensor/actuator suite while also providing for fault tolerance during on-orbit operations



- Modularity in FSW accommodates distributed processing where elements of the application can be executed on different SPA processing elements
  - Allows for reuse and reconfiguration
  - Provides fault tolerance for environment hardware failures allowing the use of commercial off the shelf (COTS) processing components

Conclusions

- Hierarchical PnP allows for the development of generic components, hardware and software, that can be interchanged at varying levels based on mission needs and requirements
- A data centric architecture also facilitates reuse of components as they become more generic
  - Atomic data removes vendor and supplier specific information
- The implementation of layered xTEDS within the SPA paradigm should be incorporated because it
  - Promotes commercial PnP concepts
  - Facilitates rapid integration of spacecraft at varying levels of components, as well as subsystems or services