Electronic Data Sheets at ESA: Current Status and Roadmap

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**Sentinel-2 In-flight Anomaly**

- **First day after launch report star trackers misaligned**
  - STR1 with STR2: 0.83 deg, STR1 with STR3: 1.1 deg, STR2 with STR3: 0.4 deg
  - Reported stable, no impact in Initial Acquisition Mode, not foreseen impact in Orbit Control Mode

- **Root cause: incorrect transformation matrix being used between Boresight Reference Frame and Alignment Reference Frame (transposed matrix shall have been used)**
  - The matrix was nearly symmetrical and mistake was not spotted
  - Wrong interpretation of ICD information

- **Sentinel-2A lessons learned: Dedicated thorough check of all configurations recommended**
  - Similar mishaps reported in other satellites
  - Taken very seriously by project and industry in before Sentinel-2B launch
  - Additional rigorous check of all configurations and calibrations implemented shortly before Sentinel-2B launch

- **Sentinel-2B in flight:**
  - Measured MIMU misalignment due to "matrix wrongly interpreted wrt direction of transformation"
  - STR quaternion not normalized due to wrong assumption (misalignment few µrads)
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**ALL OF THIS WOULD BE AVOIDED IF ICD WAS UNAMBIGUOUS AND USED CORRECTLY**
Electronic Data Sheets (EDS) – What is it?

• Machine-readable mechanism to describe data interfaces of electronic units onboard spacecraft
  • Sensors, actuators
  • Other units (PCDU, RIU, Solid State Mass Memory)
  • Instruments

• Objective: Replace paper ICDs and data sheets which accompany each device and are necessary to determine the device operation and how to communicate with it
  • Initially functional/data handling (i.e. TM/TC ICD)
  • But gradually also electrical, thermal, mechanical
Electronic Data Sheets – Use Cases

- Human Readable ICDs
- System Database
- Unit Supplier’s Proprietary models
- Electronic Data Sheet
- Simulation Models
- HW-SW Integration Tests
- Flight Software
Electronic Data Sheets – Multiple Domains

- Human Readable ICDs
- System Database
- Operations
- AIT/AIV
- Simulation Models
- EGSE development and validation
- HW validation
- Unit requirements
- Unit Supplier’s Proprietary models
- HW-SW Integration Tests
- FSW development and V&V
- Fight Software

Electronic Data Sheet

- Spacecraft Engineering
- System Database
- Operations
- AIT/AIV
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CCSDS SOIS EDS (SEDS) Overview

**XML Schema**
- Based on Red Book CCSDS 876.0-R-2
- ~276 requirements on SEDS schema elements
- XML schema provided
- 3 main elements: Data Type, Interface Type, Component Type
  Types, Interfaces, Parameters, TM/TC Packets, State machines
- Organised and grouped inside Namespace elements

**Dictionary of Terms (DoT)**
- Based on Red Book CCSDS 876.1-R-2
- Vocabulary to annotate data interfaces in Electronic Data Sheets
- It contains the ontology of the types used in the EDS
  Standard DoT vs. User-Defined DoT
Electronic Data Sheets – System View

- **EDS** describes concrete interfaces of Physical Devices
- **EDS** describes interfaces of HW/SW interaction layer
- **EDS** describes interfaces of SW Components
- **EDS** describes interfaces of Spacecraft

**Access**
- D1 FI
- D1 + D2 FI
- D3 FI
- 1553 Access
- RIU Access
- SwW Access
- RS422 Access

**Sub**
- PS
- MAS

**OBC 1**
- Software Bus Adapter
- SW Bus
- Spacecraft Interface (Data Handling)
- TM/TC Access

**Mission Control System**
Electronic Data Sheets – Status Today

- ESA conducted several studies in 2013-2016
  - Understanding requirements, process, tools, format, use, semantics
    Contributing to CCSDS XML Spec for EDS
    Initial focus mostly on FSW generation and data handling
    Focus on SOIS reference architecture (Device Access Service, Device Virtualization Service)

- EDS of several avionics units (developed with the help of unit suppliers)
  Jena Optronics Astro APS star tracker
  Sodern Hydra star tracker
  TAS UK MEMS Rate Sensor (MRS)/SiREUS
  FOG Astrix 120 Gyro
  NPAL Camera
Electronic Data Sheets – Status Today

• (continuation)
  • Improving ESA’s reference EDS tool chain
    EDS validation
    FSW code generation (C language)
    HTML generation
  • EDS verification using communication log produced by real HW
    Checking telecommands and telemetry, checking protocol using state machines
  • Using the star tracker EDS with the star tracker simulator
    Checking commands, checking responses, injecting commands
  • Automatically generating HTML documentation
    Human readable ICD
    Test report against EDS, including TM/TC coverage
Electronic Data Sheets – Status Today

- **Standardization in CCSDS with other agencies (NASA primarily)**
  - **End of 2016: Finished second agency review of two EDS books**
    - XML Specification for Electronic Data Sheets for Onboard Devices and Software Components (876.0)
    - Specification for Dictionary of Terms for Electronic Data Sheets for Onboard Components (876.1)
  - **CCSDS plan for 2017-2018**
    - Updating “Electronic Data Sheets and Common Dictionary of Terms - Overview and Rationale” Green Book (870.1)
    - Prototyping tool chains
    - Interoperability tests
      - Interoperability test plan
    - Two interoperable prototypes (ESA and NASA toolchain)
    - Mimicking scenario of NASA instrument onboard ESA satellite, interface defined in EDS (e.g. ESA JUICE mission to icy moons of Jupiter with NASA UVS instrument)
Electronic Data Sheets – Roadmap

- **Starting “SAVOIR Electronic Data Sheet Definition” activity**
  - Planned Kick Off end of 2017/beginning of 2018
  - Planned with heavy involvement of ESA Primes
  - Broader system-level view
  - User requirements, reference process
  - Focused primarily on Data Handling and Electrical ICD
  - SAVOIR EDS Data Model definition
  - SAVOIR EDS Common Toolset development
  - A number of use cases and prototypes
    - Generation of engineering/V&V/simulation artefacts
  - Feedback to standardization (CCSDS)
Looking 10 Years Back: Software Crisis

• Mid 2000s: “European Space Software Crisis”
  • Explosion of flight software complexity (cf. NASA FSW Complexity Report 2009)
  • Ad hoc fault management (cf. NASA Fault Management Workshop 2008)
  • Underestimating system impact of software
  • Flight software development driving schedules of missions (late change, delays)

• Proposed solutions (in various ESA reports 2004-2009)
  • New system and software engineering methods
  • Early modelling, simulation and prototyping
  • Code generation, test generation
  • Standardisation
  • Incremental development
  • Reuse
  • Tools allowing all this
Looking 10 Years Back: Is FSW Crisis Over?

**Today: Solutions proposed above seem to work (kind of)**

- Early FSW validation on software-in-the-loop simulators (HW emulation of onboard computer) and HW-in-the-loop simulators
- Incremental development (early FSW versions released to support spacecraft testing)
- Software frameworks
  - To facilitate reuse (heavy reuse via product lines)
  - To facilitate "variability factors" (different avionics, comms bus, CPU, mission tailored requirements)
- Modelling, code generation (mostly GNC)
- Evolution towards Integrated Modular Avionics (IMA) and integration of software functions with different criticality
- Standardisation (Independent SW V&V Guide, Packet Utilization Standard (PUS), Onboard Control Procedures (OBCP), Generic specifications (SAVOIR initiative), SMP2 standard for simulators, Improved ECSS standards)

**EDS going further in this direction:**

- Modelling, artefact generation, model consistency, digital engineering
Will EDS succeed? When? Why?

• **It is feasible!!!**
  - Simple “semi-formal” models, model transformations
  - The key thing is to standardize (contents and format)
  - ... but not everything!
    - FSW framework proprietary
    - SRDB proprietary
    - Tools as well!

• **Increasing interest in industry**
  - Making life easier (automatic flow of engineering data, inherent consistency, data validation)
  - Saving time/money/resources by reusing engineering data
  - Technology is available to do this
  - Evolution towards **Digital spacecraft engineering** is ongoing
Gathering Momentum

- **Different parts of ESA interested**
  - E.g. SIMULUS operations simulator models derived from EDS
  - Possibility to use EDS for programmable RIU
  - Possible use in early Concurrent Design Facility studies

- **International partners interested**
  - NASA, CNSA, CNES, DLR, ...
  - Provides a great tool for interoperability (within the same spacecraft, spacecraft to spacecraft, system of multiple spacecraft)
    - Interfaces described in standardised machine understandable unambiguous format
    - Proprietary tools available to support system engineering on both sides without necessity to use the same architecture/standards (e.g. ESA’s PUS encoded in EDS)

- **We need unit suppliers to get involved even more**
  - Making life easier (unambiguous ICD)
  - Such models already exist today but they are proprietary
  - Competitive advantage (provide units accompanied with standardized electronic ICDs)
THANK YOU

Questions?

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Backup Slide: Looking 10 Years Ahead

• A lot of algorithms and applications on FPGAs
  • Missing ECSS engineering standard

• Integrated Modular Avionics
• Multicores (ESA’s presentation at FSW’15)

• Agile software development

• Machine learning
  • AI augmented GNC
  • Pattern recognition
  • Intelligent mission planning