Simulation and Analysis of an Earth Observation Mission Based on Agile Platform

Augusto Caramagno
Fabrizio Pirondini
Dr. Luis F. Peñín
Advanced Projects Division
DEIMOS Space S.L.
Engineering activities and assets: EO Missions

- SPECTRA Phase A (Mission Analysis and E2E Simulator)
- EarthCARE Phase A
- GMES Sentinel Architecture Studies
- GMES Sentinel-3 Definition Phase
- Study on the use of EP for RS SC
Agile Platform Simulator Overview

- MATLAB-based mission simulator, composed of a set of Matlab/Simulink models, supported by a MMI.
  - Quantitative assessment of the performance of different mission implementation options.
    - Mission planning scheme
    - Attitude profile constraints
    - Available GS
  - Tool conceived for the simulation and optimisation of the complete mission chain, covering the three segments
    - Space
    - Ground
    - User segment (observation sites)

- Main functions:
  - Analysis of Mission Design and Scenario.
  - Test bench for Design and Optimisation of Mission Operations.
  - Mission Design Consolidation and Performance Assessment.

- Application on SPECTRA mission scenario
Agile Platform Simulator Overview

- **Mission scenario**
  - Space Segment
  - User Segment
  - Ground Segment
- **Functionalities**
  - Mission Analysis
  - Timeline Optimisation & Execution
  - Mission Operations and Budgets
- **Image acquisition Modelling**
  - Observation geometry optimisation
  - Agility and Payload Constraints
- **Inputs**
  - Scenario Definition
  - AOCS Accuracy
  - AOCS Restitution Accuracy
- **Output:**
  - Effective kinematics
  - Estimated position and pointing
SPECTRA Phase-A: Mission Analysis and Operations

- SPECTRA operation concept is based on sequences of 7 multi-directional observations of specific sites, in order to acquire information for BRDF modelling as a function of:
  - Observation-zenith angle (OZA)
  - Solar incidence angle (SZA)
- Mission planning has to determine the best series of acquisition sequences
  - Management of site acquisition conflicts
  - Management of the satellite resources
  - Scientific requests & availability of the field segment
- Constraints at system-level have to be taken into account
  - Availability of space, ground and user segments
- In the instrument imaging mode, the ADCS follows a pre-defined attitude profile, aiming instrument line of sight at the target site.
- Mission Planning prototype is based on a ground preparation of a reference operation plan, converted into attitude profiles uplinked to the satellite.
Agile Platform Simulator: Functionalities

- **Mission modelling**
  - Mission scenario analyses
  - Number of image acquisitions
  - Conflict analysis
  - Ground station coverage
  - Perturbation Analysis

- **Timeline optimisation**
  - Image acquisitions sequence
  - Ground station contacts
  - OZA sequence

- **Timeline execution**
  - Orbit and attitude profiles
  - Various AOCS modes
  - LOS Kinematics
• It is possible to simulate Agile Platform missions on various time scales ranging from a few seconds to mission lifetime.
• This allows to evaluate the feasibility of the baseline mission and its expected performances.
• Three main simulation timescales are foreseen:
  - **Long term** simulation (from one repeat cycle to a few years) → *Mission Performance Evaluation*
  - **Medium-short term** simulation (one repeat cycle or less) → *System Budgets*
  - **Image sequence** simulation (one image sequence) → *Generate LOS Kinematics as input to Image Quality Simulator*
The timeline optimisation over a whole year is intended to:
- Evaluate the proposed calendar of user requests, in terms of feasibility and completeness
- Determine the fulfilment of the calendar and the available overhead observation margin
Medium-term simulation: Timeline optimisation

- Spanning a repeat cycle (14 days), allows the mission analyst to study aspects like:
  - Orbit propagation results (orbit and attitude profiles for system-level analyses)
  - Distribution of conflicts between the sites
  - Selection of the passes in the timeline optimisation
  - Total number of image acquisitions per orbit and selected events
  - Ground station contacts optimisation with different criteria
  - Distribution of the ACT at PCA for each site
  - Optimisation of the intermediate observation OZAs for each site
  - Spread of the Phase Angle sampling for each site
  - Compatibility between the agility constraints and the selection of the intermediate OZAs.
Medium-term simulation: Timeline execution

- **Output:**
  - Orbit and attitude profiles
    - Commanded
    - Estimated
    - Effective
  - Simplified target-pointing during image acquisition
  - Cold-space calibration, transitions

- **Data to system-level analyses:**
  - System budgets
  - Power budgets
  - Thermal analyses
  - Platform agility analyses
Short-term: Instrument LOS kinematics generation

- Orbit and attitude profiles are computed for a complete image acquisition sequence (7 scenes):
  - Commanded
  - Estimated
  - Effective

- The S/C follows 3 pointing laws during the simulation:
  - Scene acquisition
  - Repositioning
  - Tranquillisation

- LOS Kinematics profiles are provided as input to an Image Quality Simulator
Short-term: Attitude guidance and control

- Agile Platform Simulator implementation of attitude guidance:
  - Nadir pointing, Sun pointing, Target Pointing and Imaging mode, Orbit control mode (dummy).
- Modes are defined by kinematics constraints:
  - Yaw steering
  - Scene scanning principle
  - Illumination constraints
- Imaging mode is configurable selecting:
  - Site location: geodetic latitude, longitude and altitude above geoid
  - Image size
  - Scanning direction with respect to SC ground track
  - Geometric/Radiometric shift cancellation
  - Pixel line integration time (slowdown factor)
- Attitude estimation: performance model (star tracker)
- Attitude control
AOCS Algorithms and Modelling

- **Mission Timeline simulation encompasses:**
  - Execution of reference mission planning
  - Modelling of attitude determination error
  - Implementation of AOCS modes and mode transition (state machine)
  - O/B Attitude guidance (nominal LOS kinematics based on orbital position or timetagged profiles) and control
Nominal and Effective Kinematics

- **Nominal kinematics**
  - Agile platform
  - Switch between pointing modes
  - Advanced control laws

- **Effective kinematics**
  - Scene acquisition
  - Repositioning
  - Tranquillisation
CMG-based Attitude Control

- Algorithm:
  - Star-tracker based AD
  - CMG based Attitude Control
  - Quaternion formulation
  - Rest-to-rest eigenaxis rotation under slew rate constraint
  - Compatible with CMG sizing) and control requirements.

- Image acquisition by a 3 manoeuvres sequence:
  - Acceleration phase
  - Coasting phase
  - Deceleration phase
CMG-based Attitude Control

- Example of Effective Profile during an Image Acquisition

Angular Velocity Components

Site = 46 - Event start time [s] = 917415 - ACT angle at PCA [deg] = 0.767

- Effective \( \alpha_x \)
- Effective \( \alpha_y \)
- Effective \( \alpha_z \)
CMG-based Attitude Control

- Attitude Control error during an Image Acquisition

![Control Error: Angular Velocity Components](image-url)

- Slu = 45 - Event start time [s] = 917415 - ACT angle at PCA [deg] = 0.767
User Interface
User Interface : Output Visualization

Output Data Visualization

Orbital Elements

Pass Geometry

Fulfilment of Agility Constraints