APISAT 2019

2019 ASIA PACIFIC INTERNATIONAL SYMPOSIUM ON AEROSPACE TECHNOLOGY

SURFERS PARADISE MARRIOTT RESORT,
GOLD COAST
4 – 6 DECEMBER 2019

ENGINEERS
AUSTRALIA

Spacecraft II

Seonho Lee

PhD

Presentation Title

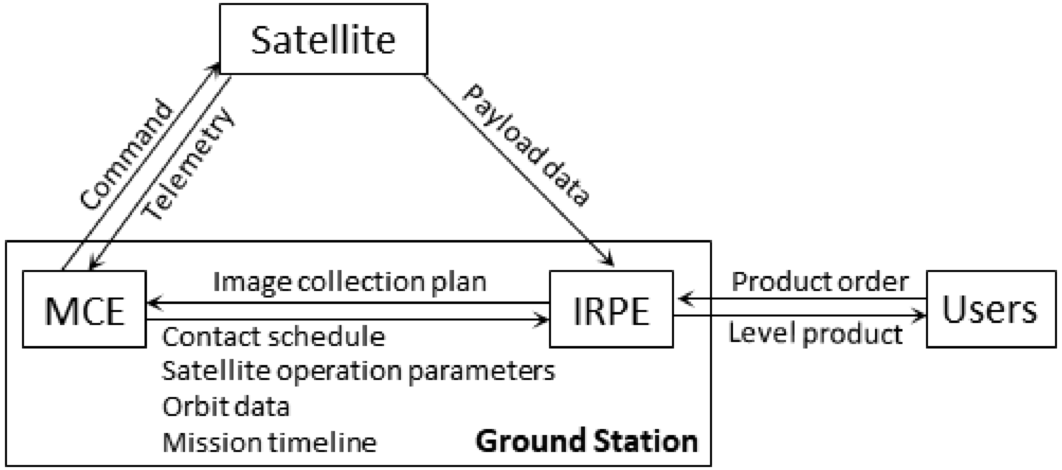
On-orbit Image Collection Re-planning Method for Earth Observation Satellites

Agenda

- Introduction
- Problem Definition
- Finding Solutions
- Performance Analysis
- Conclusions

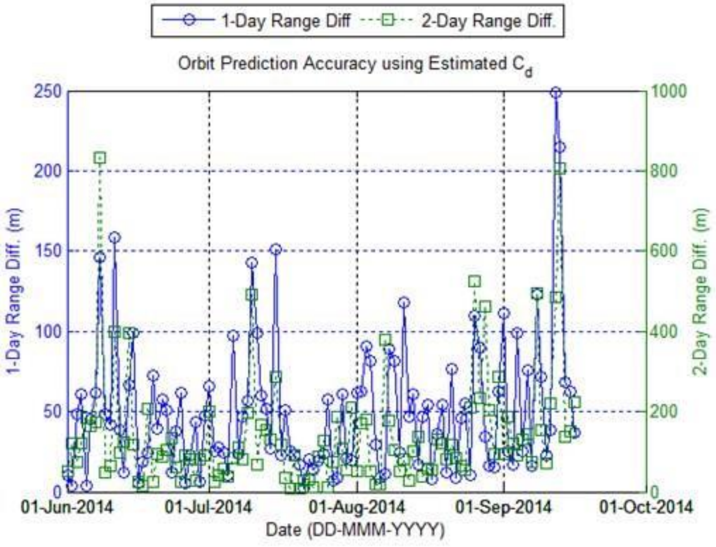
Ground Station

- **Mission Control Element (MCE)**
  - ✓ **Analyze the satellite orbit and attitude**
  - ✓ **Determine the satellite operation orbit using**
    - ➢ Onboard GPS navigation solution
    - ➢ Ground-based antenna tracking & ranging data
  - ✓ **Generate a variety of orbit data**
    - ➢ Orbit ephemeris data in position & velocity
    - ➢ TLE (two-line-element) in orbital elements
    - ➢ Orbit propagation data for mission planning & antenna tracking
- **Imagining Reception & Processing Element (IRPE)**
  - ✓ Receive RF signal from the satellite
  - ✓ Retrieve raw data, generating the image products
  - ✓ Provide the level products to users



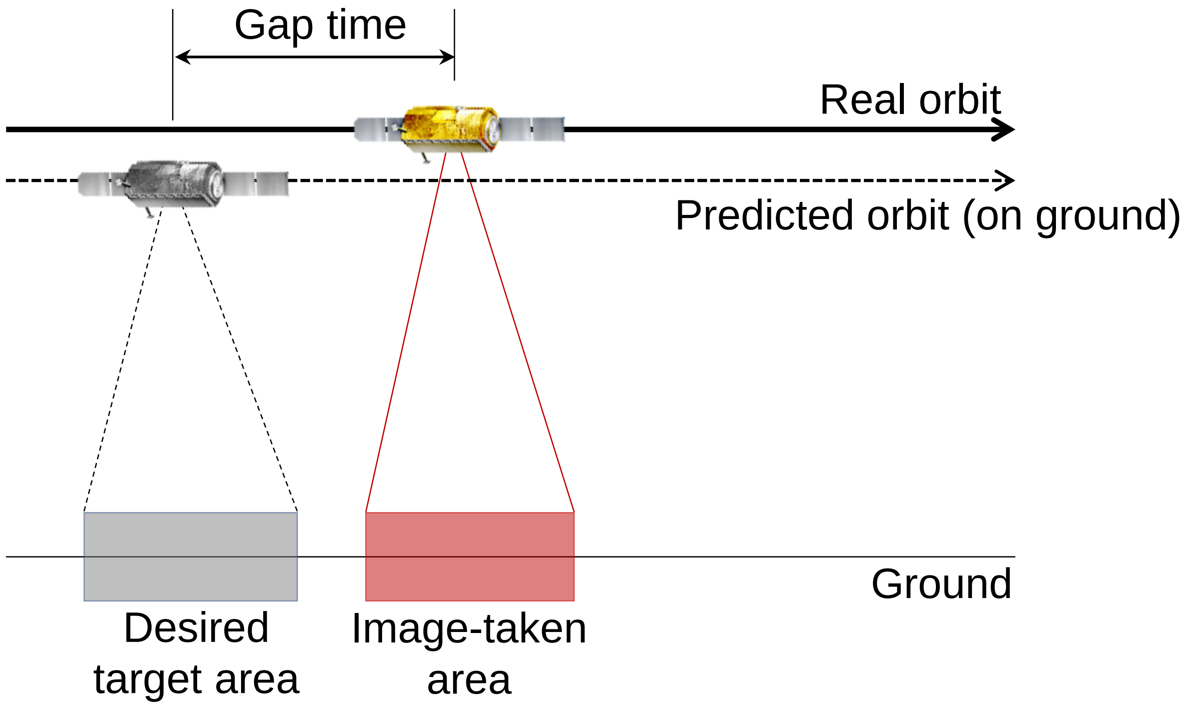
Limitation of Conventional Imaging Collection Planning

- **Orbit Prediction**
  - ✓ **Numerical high-precision orbit propagator**
  - ✓ **Based the latest estimated state vectors**
  - ✓ **Perturbation models**
    - ➢ Higher-order gravitational force of Earth, atmospheric drag, Sun & Moon attraction, solar radiation pressure, and etc
  - ✓ **Uncertainties**
    - ➢ Un-modeled acceleration, model mismatch, numerical error, varying solar activities, and etc
  - ✓ **Prediction Accuracy (mostly occurs in along-track)**
    - ➢ ~ 200 m in one day
    - ➢ ~ 1 km in two days



- **Orbit Prediction Error Gives Impacts to**
  - ✓ Product coverage location for EO/IR/SAR satellites
  - ✓ De-correlation of interferometry application for SAR satellites

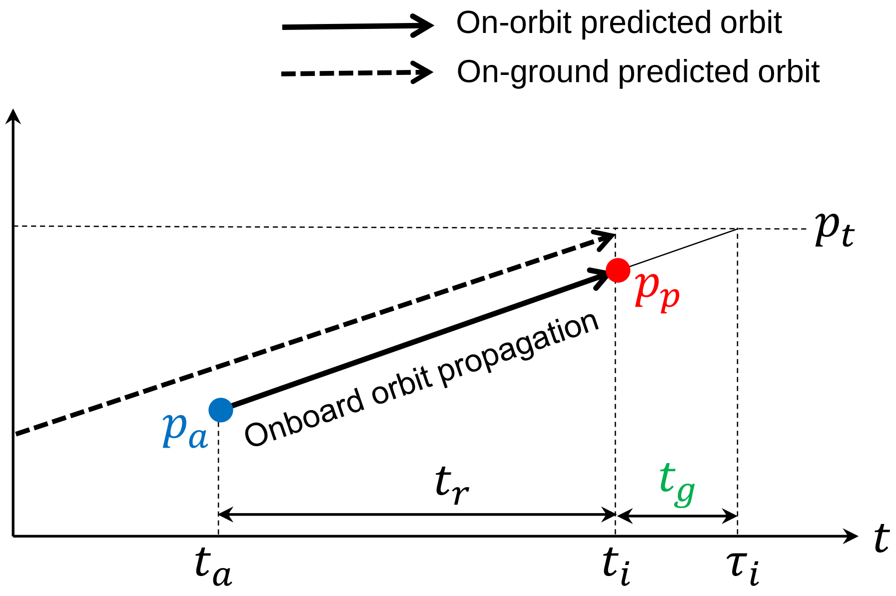
Problem Definition of Imaging Collection Re-Planning



- **Problem**
  - ✓ Find and compensate the gap time
- **Constraints**
  - ✓ No contact during imaging
  - ✓ No real-time support from ground station
- **Proposed Solution**
  - ✓ Just before imaging
  - ✓ Estimate the gap time using onboard resources
  - ✓ Correct the imaging time

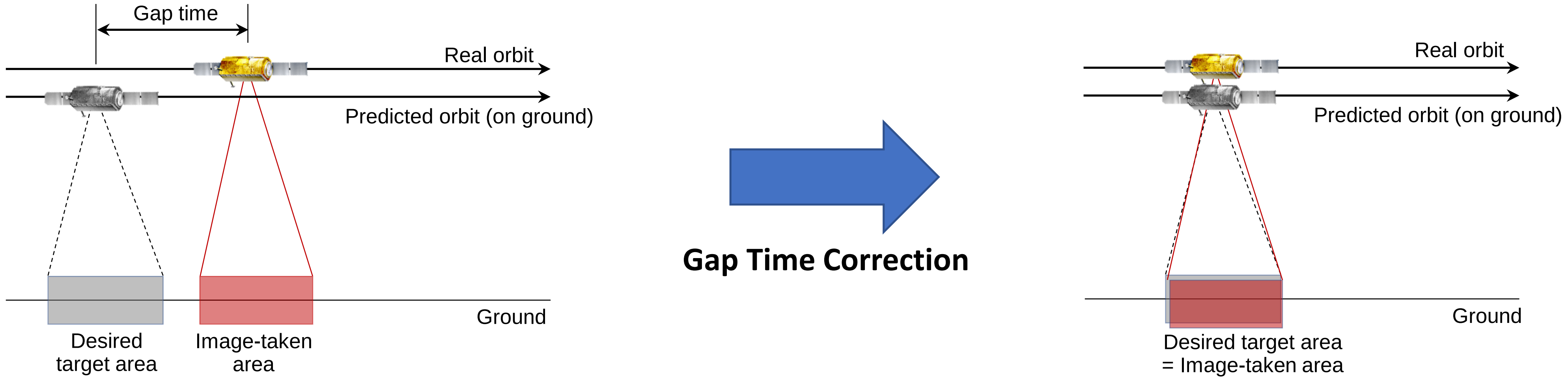
Operation Flow of Imaging Collection Re-Planning (1/2)

- **In advance before activating the re-planning,**
  - **0. GS uploads the following information**
    - Target position(p_t), original imaging time(t_i)
    - Re-planning activation time(t_a)
- **At the activation of the re-planning,**
  - **1. Calculate the residual time(t_r)**
    - $t_r = t_i - t_a$
  - **2. Obtain the current GPS data in ECI frame(p_a)**
  - **3. Run the onboard orbit propagator**
  - **4. Obtain the position & velocity past residual time(P_p, V_p)**
  - **5. Calculate gap time(t_g)**
    - $t_g = |p_t - p_p| / |v_p|$
  - **6. Obtain the corrected imaging time(τ_i)**
    - $\tau_i = \tau_i + t_g$



$$d_g = p_t - p_p$$
$$t_g = \text{sign}(d_g \cdot v_p)\, |d_g| / |v_p|$$

Operation Flow of Imaging Collection Re-Planning (2/2)



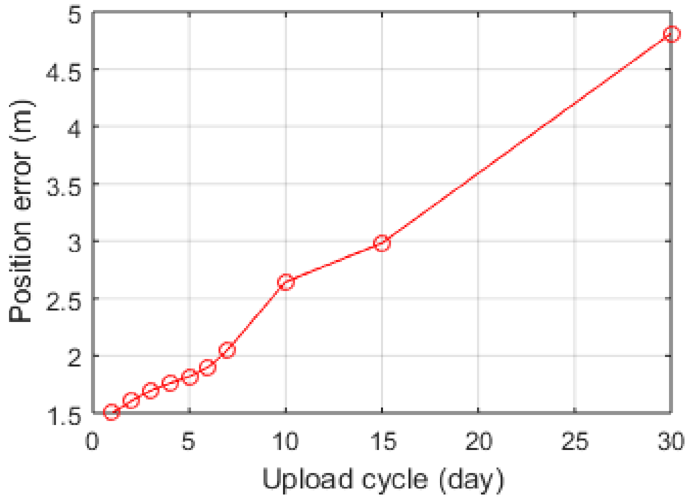
Performance Analysis (1/3)

- **ECEF-to-ECI Coordinate Transformation**
  - ✓ **GPS navigation solution (p_{ecef}, v_{ecef}) in ECEF frame is obtained from onboard GPS receiver**
  - ✓ **Should be converted into ECI frame**
  - ✓ **Parameters in DCM**
    - ➢ Polar motion (M_{pol}), earth rotation (M_{rot}), nutation (M_{nut}), precession (M_{pre}), and bias (M_{bias}) models
    - ➢ Released by IAU/SOFA (International Astronomical Union/Standards of Fundamental Astronomy)
    - ➢ To use the earth rotation and polar motion mode, should upload the polar motion data (x_p, y_p) and the UTC time correction data ($\Delta UT1$) to the satellite periodically
  - ✓ **Position (p_{eci}), velocity (v_{eci}) in ECI frame**

$$p_{eci} = M_{bias} M_{pre} M_{nut} M_{rot} M_{pol} p_{ecef}$$

$$v_{eci} = M_{bias} M_{pre} M_{nut} M_{rot} M_{pol} v_{ecef}$$

Accuracy according to upload cycle of both polar position and UTC time correction data

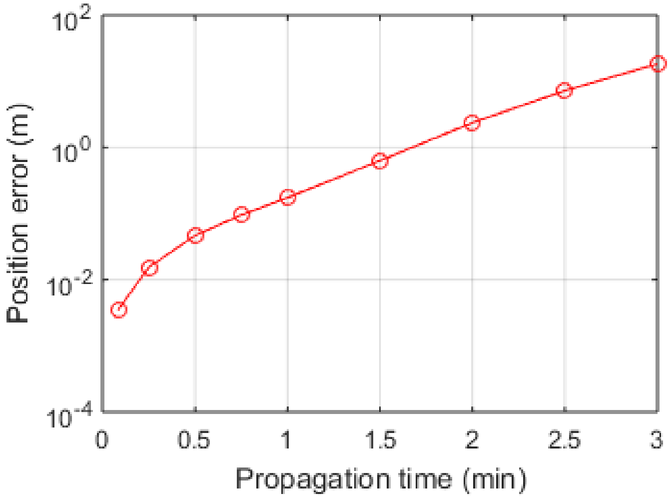


Performance Analysis (2/3)

- **Onboard Orbit Propagation**
  - ✓ **Onboard orbit propagator with J2 perturbation**
  - ✓ **Initial condition**
    - ➢ Position (p_{eci}), velocity (v_{eci})
  - ✓ **Propagation time**
    - ➢ Residual time (t_r)
  - ✓ **Find future position (p_p) and velocity (v_p) past residual time (t_r)**

$$(p_p, v_p) = \text{ORBIT\_PROPAGATOR}\ (p_{eci}, v_{eci}, t_r)$$

Accuracy according to residual time



Performance Analysis (3/3)

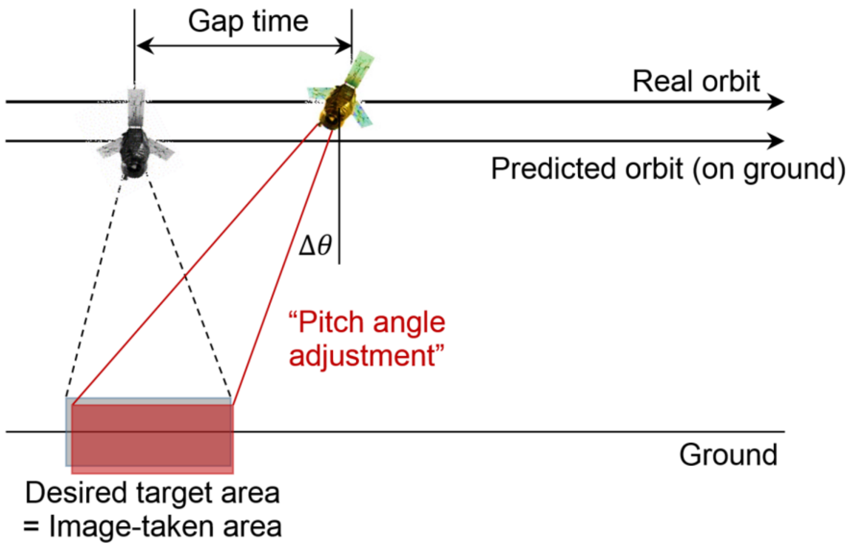
- **Budget of Product Coverage Location**

Contribution Factor	Capability	Remark (Assumptions)
GPS Receiver	5 m	Typical value
ECEF-to-ECI Conversion	1.5 m	Uploading polar motion and UTC correction daily
Onboard Orbit Propagation	1 m	J2 consideration
Pointing Error (applicable only for EO/IR satellite)	105 m	Pointing accuracy: 0.01 deg Orbit altitude: 600 km
System error	5 m	Sync error, timing error, system delay, and etc.
RSS Sum SAR Satellite EO/IR Satellite	 **7.3 m** **105.3 m**	 Req’t : OO m Req’t : O km

Alternative Solution: Pitch Angle Adjustment

- **In case of correcting the imaging time in payload is not feasible due to the bus-payload interface design & operation constraints**
- **Pitch angle($\Delta\theta$) is simply calculated using**
  - ✓ **Satellite velocity(v_p)**
  - ✓ **Gap time(t_g)**
  - ✓ **Orbit altitude(h)**

$$\Delta\theta = \mathrm{atan}\left(\frac{\|v_p\| t_g}{h}\right) \cong \frac{\|v_p\| t_g}{h}$$



Conclusions

- **Cover the necessary operation concept, architecture, and module constitution for on-orbit image collection re-planning**
- **Provide the performance analysis results for each module**
- **Provide the product coverage location budget analysis for SAR satellite**
  - ✓ The conventional method gives OOO m of positioning error and becomes even worse as the prediction day goes by.
  - ✓ However, the proposed method guarantees positioning error within O m always regardless of the prediction day.
- **The proposed re-planning method is implemented to KOMPSAT-6 satellite (SAR payload), which will be launched in 2021.**