Interim Report of the COMS INR Performance Enhancement through the 1st Four Years of Normal Operation

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Background (1): COMS

COMS (Communication, Ocean and Meteorological Satellite) : Geostationary, multi-mission* satellite

*COMS Missions
A meteorological mission (MI: Meteorological Imager)
An ocean imager mission (GOCI: Geostationary Ocean Color Imager)
An experimental Ka band telecommunication mission

Mass at Launch: 2460 kg
Power : > 2.5 KW (@ EOL)
Orbital Location: 128.2°E
Operational Life time: 7.7 years, Design Life time: 10 years

Launched @ June 26, 2010, 21:41 (UTC) by Ariane 5 ECA
Background (2): Image Processing

“Image”:

```
Raw Image
  ↓
L1A Image
  ↓
L1B Image
```

- Radiometric Calibration
- Geometric Correction: INR (Image Navigation & Registration)
- Pre-processing
- Post-processing
**Background (3): INR (in a Nutshell)**

- Thermo-elastic Deformation Model
- Instrument Misalignment Model
- Orbit elements / ephemeris (parameters)
- INR Reference Measurements & Determination
  - Landmarks
  - Stars
  - * GPS

State Vector Estimation/Correction Info. Generation

- Estimated State Vector
- Resampling

- (Core INR)
- L1B Image/HRIT, LRIT

\[SV\text{ normally consists of Attitude, Orbit, and Misalignment angles.}\]
## Background (4): Evolution & Comparison of INR Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Estimation algorithm</th>
<th>Timeliness</th>
<th>Reference measurements</th>
<th>Function (processing) allocation</th>
<th>Req. Spec. (&amp; Typical performances)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOES I~M</td>
<td>A priori Least Square</td>
<td>Timeliness: 0.7 minutes from start of image</td>
<td>Landmarks + Imager Stars</td>
<td>On-board + Ground</td>
<td><strong>112 µrad</strong></td>
</tr>
<tr>
<td>GOES N~P</td>
<td>A priori Least Square</td>
<td>Timeliness: 0.7 minutes from start of image</td>
<td>Landmarks + Imager Stars</td>
<td>On-board + Ground</td>
<td><strong>56 µrad</strong></td>
</tr>
<tr>
<td>MTSAT-1R</td>
<td>A priori Least Square</td>
<td>Timeliness: 3 minutes from start of image</td>
<td>Landmarks + Imager Stars</td>
<td>Ground processing</td>
<td>Vis: Vis pixel IR: 1R pixel (rms)</td>
</tr>
<tr>
<td>MTSAT-2</td>
<td>A priori Least Square</td>
<td>Timeliness: 3 minutes from start of image</td>
<td>Landmarks</td>
<td>Ground processing</td>
<td>Vis: Vis pixel IR: 1R pixel (rms)</td>
</tr>
<tr>
<td>COMS</td>
<td>A posteriori Least Square</td>
<td><strong>Timeliness: 12 Minutes from end of Image</strong></td>
<td>Landmarks</td>
<td>Ground processing</td>
<td><strong>56 µrad</strong></td>
</tr>
<tr>
<td>GOES-R</td>
<td>Kalman filter</td>
<td>Timeliness: Near real time</td>
<td>Imager Stars + GPS</td>
<td>On-board + Ground</td>
<td><strong>21 µrad</strong></td>
</tr>
</tbody>
</table>
Motivation

- Let us improve ‘COMS INR operational performances’:
  - centered around the ‘timeliness’ performance
  - dissect and identify the good, the bad, and the ugly in COMS INR design
  - maintain/expand the good, improve/replace the bad, and clean up/simplify/discard the ugly
  - see if we can enhance other INR performance metrics alongside
Summary of the Efforts (1)

‘Delta INRSM’

“Improved version of COMS INRSM* in timeliness and potentially in INR performance metric as well, by replacing the least squares with Kalman filter and by ensuring all the interfaces and ops cond.”

*INRSM (INR Software Module)
Summary of the Efforts (2)

- Delta INRSM development log

  - Revisit of COMS INR design and feasibility study on the reusability of COMS INR algorithm for the future (2011. 10. 1 ~ 2012. 4. 30)

  - COMS INR Kalman filter Algorithm (CIKA) development (2011. 10. 1 ~ 2012. 4. 30)

  - COMS INR Simulator development (2013. 1. 21 ~ 2013. 7. 20)

  - CIKA refinement & optimization for the implementation into COMS INRSM (2013. 8. 21 ~ 2013. 12. 30)

  - Delta INRSM implementation (2013. 12. 21 ~ current)
Summary of the Efforts (3)

Key Objectives in Delta INRSM development

- Maximal re-use of COMS INRSM’s ‘good’ heritage (Landmark Determination, Navigation Equation, Re-sampling) in documentation, source code, database
- Replacement of Least Squares by Kalman filter
- Minimum change of algorithm and coding from the operational INRSM
- Aim for performance enhancement in the timeliness
- Aim for a more consistent and potentially improved navigation/registration performances
- Aim for an overall framework of generic, standardized INR system development, validation and operation
## Key Results and Implications (1)

### Summary of the current outcome and the overall status

<table>
<thead>
<tr>
<th></th>
<th><strong>Timeliness</strong>* (min.)</th>
<th><strong>Navigation Error (EW/NS) (µrad, 3-sigma)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FD</td>
<td>ENH</td>
</tr>
<tr>
<td><strong>INRSM</strong></td>
<td>Wait</td>
<td>No-Wait</td>
</tr>
<tr>
<td></td>
<td>10:25</td>
<td>3:02</td>
</tr>
<tr>
<td><strong>INRSM-r</strong></td>
<td>Wait</td>
<td>No-Wait</td>
</tr>
<tr>
<td></td>
<td>(7 TBC)</td>
<td></td>
</tr>
<tr>
<td><strong>Delta INRSM</strong></td>
<td><strong>1:44</strong> (r=0.1)</td>
<td><strong>1:50</strong> (r=0.1)</td>
</tr>
<tr>
<td></td>
<td><strong>1:59</strong> (r=0.14)</td>
<td><strong>1:57</strong> (r=0.14)</td>
</tr>
</tbody>
</table>

*: as per timeliness definition of COMS req. spec.
**: courtesy of KMA test/analysis result (72hrs data)
***: courtesy of Satreci test/analysis result
****: courtesy of KARI test results (backup real-time system in KARI GS)
☞: r='landmark reliability’ (minimum reliability)
Key Results and Implications (2)

Simulation result (1) – Residual (Navigation Error)
Key Results and Implications (3)

Simulation result (2) – Registration Error (15 min, f2f)
Key Results and Implications (4)

Simulation result (3) – Registration Error (90 min, f2f)
Key Results and Implications (5)

Simulation result (4) – Registration Error (24hr, f2f)
Key Results and Implications (6)

Delta INRSM (vs) INRSM – Residual (Navigation Error)
Key Results and Implications (7)

**Delta INRSM: CorrAngles**

![Graph showing Delta INRSM: CorrAngles](image)
Key Results and Implications (8)

Delta INRSM: Misalignment
Key Results and Implications (9)

Delta INRSM Sample Test Result:
(2014-08-08 ~ 2014-08-10, r=0.13)
Key Results and Implications (10)

Generic INR Architecture

- **Instrument Payload IMC** (Image Motion Compensation)
- **AOCS** (On-board computer)
- **Data Distribution**
  - Raw Image/star data/S/C attitude data
  - Level 0 data
- **Radiometric Calibration**
- **Landmark and Star Determination**
  - Landmarks, Star residuals
- **Navigation & Registration Filter (Kalman Filter)**
  - State Vector
  - Thermo-elastic data generation
  - (** State Vector Propagation & Estimation**)
- **Resampling**
- **HRIT/LRIT Generation**
  - Level 1B data
  - Level 1B data/HRIT/LRIT data
- **Image Quality Control**
  - S/C attitude data
  - State Vector
  - Star data
- **IMC State Vector**
- **Thermo-elastic data**
- **Level 1B (Core INR)**
  - Orbit
  - Landmark/Star Residual Statistics
- **Resampling**

(* Uses ‘Navigation Equation’*)
Conclusion & Suggestion

• COMS INR performance enhancement is pursued and being achieved for the enhancement of COMS MI data application and utility to its maximal capability, for the remainder of COMS MI mission operation, and also as the preparation for the follow-on missions.

• A foundation for the expansion of INR technologies is established, by systemizing the technical findings, breakthroughs and lessons obtained through this work.

• ‘Chopstick culture’ and regional collaboration: “In the grand scheme, it is the time to call for more proactive collaborations among nations in this region, not only in the user perspectives but also in the development aspects.” (re-quote from AOMSUC-3)