Applications of Time-Frequency and Hilbert-Huang Transform (HHT) to FORMOSAT-3 Satellite System Key Parameters Trending Data Studies

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Outline

- Introduction
- Source Data Preparation
- Key Parameter Data Trending – HHT & STFT
- Conclusion
Introduction

- The Hilbert-Huang transform (HHT), a NASA designated name, is a newly developed adaptive data analysis method and has been used extensively in geophysical, vibration, acoustic, underwater, biomedical system, and other researches.
- No research results of satellite trending data using HHT method were found in the public domain.
- Other than traditional trending method, Time-Frequency Analysis and HHT method are used to FORMOSAT-3 constellation for trending and degradation data analysis on some satellite key system parameters.
- The satellite data used covers 30 satellite-years (= 6 satellites x 5 years) in-orbit data.
- Preliminary results are presented here to show the value of using the methods we applied.
Introduction (Cont.)
- Hilbert–Huang transform (HHT) -

• The HHT provides a new method of analyzing non-stationary and non-linear time series data.

• The HHT uses the Empirical Mode Decomposition (EMD) method to decompose a signal into so-called intrinsic mode function (IMF), and uses the Hilbert spectral analysis (HSA) method to obtain instantaneous frequency data.

\[ h(\omega) = \int H(\omega, t) \, dt \]
\[ X(t) = \sum_{j=1}^{\infty} a_j(t)e^{\frac{j\pi}{T}(t-t_0)} \]
\[ Y(t) = \frac{1}{\pi} \text{PV} \int_{t_0}^{t} \frac{X(t')}{t-t'} \, dt' \]
Introduction (Cont.)
- Short-Term Fourier Transform (STFT) -

- Frequency at a certain time is a distribution obtained from Fourier transform. The short period of signal applied to the Fourier transform contains the specific moment of interest.

- In time-frequency analysis, such idea evolves as the Short-Term Fourier Transform (STFT).

\[ F(t, \omega) = \int_{-\infty}^{+\infty} f(\tau) g(\tau - t) e^{-i\omega \tau} d\tau \]

Note g is a windowing function. For Gaussian window, the transform is also known as Gabor Transform.
Satellite Source Data Preparation

- Source data: 1 value/day vs. 1 value/minute.
- Satellite key system parameters including:
  - Satellite sun beta angle,
  - EPS (Electrical Power Subsystem) Battery Parameters
    - Bus Voltage, Battery State-of-Charge (SOC), Battery Pressure (1&2), Battery Temperature (1&2), Battery Current, and Battery Output Power.
  - ACS (Attitude Control Subsystem)
    - ACS Mode, ACS Raw/Pitch/Yaw Attitude, Wheel Speed, Wheel Current, Wheel Temperature, and Wheel Friction Coefficient
  - C&DH (Command and data Handling Subsystem)
    - Flight computer (FC) reboot/reset event, Attitude Control Electronic (ACE) reboot/reset event, Battery Charge Regulator (BCR) reboot/reset event
  - Payload Subsystem
    - GOX Temperature, GOX Signal-to-Noise Ratio (SNR), GOX payload on percentage, and GOX Radio Occultation (RO) events.
**Analysis Tools**

- **New Analysis Method**
  - Visual Signal Tool
    - Hilbert-Huang Transformation (HHT)
    - Time Frequency Method (Short-Term Fourier Transform, STFT)

- **Traditional Method**
  - **PV-WAVE**: support spacecraft and payload instrument SOH data trending
  - **Archive Browser Extractor (ABE)**: provide short-term and long-term data trend
  - Matlab
  - Excel Spreadsheet,…etc
Spacecraft & Payload Configuration

- GPS Occultation Experiment (GOX)
  - Primary – B Side
  - Secondary – A Side
- GOX POD2 Antenna
- GOX POD1 Antenna
- BATTERY
- Reaction Wheel Assembly
- Flight Computer (FC) Attitude Control Electronics (ACE)
- GPS Occultation Experiment (GOX)
- Tiny Ionospheric Photometer (TIP)
- Tri-Band Beacon (TBB) Electronics
- GOX Occultation Antenna (OCC1 ANT)
- Battery Charge Regulator (BCR)
- GOX OCC2 Antenna
- TBB Antenna
Start with Sun Beta Angle?

- Sun **beta angle** ($\beta$) is a value used mostly in spaceflight.
- Sun **beta angle** determines the percentage of time a spacecraft in low Earth orbit (LEO) spends in direct sunlight, absorbing solar energy.
- Beta angle $\equiv$ the angle between the orbit plane and the vector from the sun (which direction the sun is shining from).
All FMs Sun Beta Angle Profile
Battery State-Of-Charge (SOC) Five Years Trend

Courtesy from: Walton Huang/NSPO
Battery capacity degrade!
Could we find out the degradation trend as early as possible!
FM1 Battery SOC (HHT/STFT)

FM1 SOC with trending

Date
2007 2008 2009 2010 2011

Capacity (Ah)
0 5 10 15

Date
2007 2008 2009 2010 2011

Frequency [cycles/day]
0 10 20 30 40 50 60 70 80 90 100

FM1 SOC STFT

Batt SOC
Batt SOC HHT Residual

Frequency [cycles/day]
0 1 2 3 4 5

NSPO 90 Years In Space
NATIONAL SPACE ORGANIZATION
FM2 Battery SOC (HHT/STFT)

**FM2 SOC with trending**

- Batt SOC
- Batt SOC HHT Residual

Date:
- 2007
- 2008
- 2009
- 2010
- 2011

Capacity (Ah)
- 0
- 5
- 10
- 15
- 20

Frequency (cycles/day)
- 0
- 10
- 20
- 30
- 40
- 50

**FM2 SOC STFT**

NSPO 90 Years in Space

NATIONAL SPACE ORGANIZATION
FM3 Battery SOC (HHT/STFT)

**FM3 SOC with trending**

- Batt SOC
- Batt SOC HHT Residual

**FM3 SOC STFT**

- Frequency [cycles/day]
- 2007 - 2011
- 0 - 100
FM5 Battery SOC (HHT/STFT)

FM5 SOC with trending

Date

Capacity (Ah)

Freq [cycles/day]

FM5 SOC STFT

Batt SOC

Batt SOC HHT Residual

Date

NATIONAL SPACE ORGANIZATION
FM6 Battery SOC (HHT/STFT)

FM6 SOC with trending

Date

Capacity (Ah)

FM6 SOC STFT

Frequency [cycles/day]

Date

NATIONAL SPACE ORGANIZATION

NSPO 20 Years in Space
Conclusion

• A preliminary results have shown a value for the application of Time-Frequency and HHT method to perform FORMOSAT-3 satellite data trending on some key parameters, especially life-limited hardware components (for example, battery in our case study).

• Further analysis on more key parameters on ACS, C&DH, and GOX Payload subsystem for all six satellites are planned in the future.
References & Acknowledgements

• Reference:

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