Review of Models for GNSS yaw attitude

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Why yaw attitude modeling?

For high precision GNSS positioning

- Orbit determination
- For correction of phase wind up due to RHCP in orientation of receiver
- Proper measurements (phase and pseudorange) due to antenna phase center eccentricity (GPS II/IIA and GLONASS-M)

It can cause 10 centimeters range error

**Attitude constraints (in S/C fixed coordinate system):**

- y-axis points towards the solar panels, perpendicular to the Sun
- z-axis (yaw) points towards the center of the Earth

  ==> satellites rotates around its z-axis (yaw steering)
Terminologies:

**Beta (β):** Elevation (acute) angle above the orbital plane. Rate of beta is about 1 deg/day. Eclipse occurs twice per year.

**Orbit Angle (μ):** Angle between S/C position vector and orbit midnight grows with the S/C motion and restricted to be [0, 360] deg. μ = 180° at orbit Noon, μ = 0° at orbit Midnight.

(Dilssner et al., 2010)
Yaw attitude is split out into three regimes:

- **Nominal yaw** \( [\psi = \text{atan2}(-\tan\beta, \sin\mu)] \): most of the time
- **Noon turn maneuver**: around \( \mu = 180^\circ \) and \( |\beta| < 5^\circ \) for all satellites
- **Midnight turn maneuver**: around \( \mu = 0^\circ \) and \( |\beta| < 13.5^\circ \)
  - **Shadow maneuver**: for all satellites
  - **Post shadow recovery**: only for GPS block II/IIA satellites
Review of Models for GNSS yaw attitude

Models:
- Bar-Sever (1996) for GPS block II/IIA
- Kouba (2008) for GPS block IIR
- Dilssner et al (2010) for GLONASS-M
Impact of Assumptions of the Models

**Problem at beta close to zero**

Ambiguous yaw rotation at start of the maneuver

Beta changes sign at $\mu = 180$ deg (orbit noon)

Jump due to implementation during the maneuver
Impact of Assumptions of the Models

Problem at beta close to zero

GPS block IIR and GLONASS-M

- Maximum 180 deg yaw error during noon and midnight maneuvers
- Jump in yaw angle during the maneuvers while beta changes its sign
- Beta rate problem can be solved by using orbits (data) from the past

GPS block II/IIA

- Maximum 180 deg yaw error during noon maneuver
- Almost no yaw error due to yaw bias as it drives the yaw angle during the shadow crossing maneuver
Impact of Assumptions of the Models

Problem at beta close to zero

How often the jumps happen?

● Max. duration of maneuvers:
  - 15 min for GPS IIR
  - 12 min for GLONASS-M

● Beta changes sign approx. twice per year:

● Probability of a jump for one satellite:
  - (2/365)*(1/24) = 2/24 per year for GPS IIR
  - (2/365)*(0.8/24) = 1.6/24 per year for GLONASS-M

For example in 2010, there were around 20 GPS-IIR and 22 GLONASS-M satellites

In total 3.1 days with a jump in 2010
Impact of Assumptions of the Models

Uncertainty in hardware rate $R$

**GPS block II/IIA (JPL estimated hardware rate)**
- Average hardware rate $R$ is 0.115 deg/sec
- 5% uncertainty in $R$ among satellites $\rightarrow R = 0.115 \pm 0.005$ deg/sec
- 10% variation between satellites of the same block

**GPS block IIR**
- No estimation but constant hardware rate $R$ is 0.2 deg/sec
- 10% uncertainty in $R$ $\rightarrow R = 0.2 \pm 0.02$ deg/sec

**GIONASS-M**
- Average hardware rate $R$ is 0.25 deg/sec
- 10% uncertainty in $R$ $\rightarrow R = 0.25 \pm 0.025$ deg/sec
Impact of Assumptions of the Models

Uncertainty in hardware rate $R$

GPS block II/IIA
- Up to 15 deg and 30 deg yaw error during noon and midnight turns
- Ambiguity in the direction of rotation of the post shadow maneuver

GPS block IIR: Up to 36 deg yaw error in noon and midnight maneuvers

GLONASS-M: Up to 18 deg and 36 deg yaw error during noon and midnight turns
Impact of Assumptions of the Models

Post shadow recovery ambiguity for GPS block II/IIA

Deviations from nominal attitude at shadow exit

error bar = eclipse duration * uncertainty in hardware rate

Depending on $\Delta \Psi$ ==> continue yawing at the same rate or yaw reversal
if $\Delta \Psi$ is close to $\pm 180^\circ$ ==> ambiguity

==> 21% probability of ambiguity for one satellite in post shadow recovery
Impact of Assumptions of the Models

Conclusions

GNSS satellites perform yaw maneuvers during eclipse seasons.

The key parameters of these models are:
- $\beta$
- $R$, hardware rate
- $b$, yaw bias (GPS II/IIA)

If $\beta$ is close to zero during the maneuver a jump may occur:
$\Rightarrow$ problem can be solved by using the rate of $\beta$

Uncertainty in nominal hardware rate, ambiguity in post-shadow maneuver may occur:
$\Rightarrow$ problem can be solved by estimating $R$
References

