Flight Test Data Validation of GPS Ranging Error Characteristics

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Introduction and Motivation

- Dual-frequency GPS signals exclude the ionosphere delays
- However, the measurement combination increases signal noises
- Carrier smoothing is developed to alleviate the ranging signal noise

- Unexpected results occur when processing the flight test GPS measurement data with algorithms developed for static receiver data processing

Shown in the followed flight test data error statistics
WAAS corrected ranging errors in the flight test

95% of Non-smoothed L1-only errors are within ±2.4m
95% of Non-smoothed dual-freq errors are within ±3.1m

Only a small increase in the noise going from L1-only to Dual-freq signal
Code Measurement Error Statistics

WAAS corrected and Carrier smoothed ranging errors

95% of Smoothed L1-only errors are within ±2.3m (±2.4m)
95% of Smoothed dual-freq errors are within ±3m (±3.1m)

Carrier smoothing did NOT effectively reduce the apparent meas. noises
Error statistics do NOT agree with well-established concepts:
- Dual-freq signals should be much noisier than L1-only signals
- Carrier smoothing should effectively reduce code meas. Noises

Are there any unidentified errors with the flight test data?

Before get into details of the data, take a brief look at the data processing background.
Flight test Data Collection and Record

Date: Sep 19th, 2006  
Site: Memphis Int’l Airport, TN  
Data: 2 sets of dual-freq 1Hz GPS data; Aircraft position data file (TSPI); WAAS broadcast messages.
Flight test Data Collection and Record

- Total 8 flight approaches: climb-keep-dive
Data Process Steps

Time and Space
Position
Information
from integrated
GPS receiver
and IMU

Aircraft
position
data (TSPI)

GPS time,
aircraft pos (LLA, ECEF),
aircraft velocity (ECEF),
DOP

GPS observation data
& navigation message

Ground and on-board GPS receivers

Ephemeris,

WAAS
correction
message

Ground and on-board GPS receivers

GPS time,
PRN, code,
carrier,
track time,
C/N₀

Ephemeris,

True ranges based
On ephemeris and
aircraft / ground
receiver pos.

Carrier Smoothed GPS pseudo-ranges

Dual-freq
• WAAS corrected

Single-freq
• WAAS corrected
Code Measurement Error Findings

Shown in the error statistics:

- Only a small noise increase for the dual-frequency signal comparing with the single-frequency signal
- The carrier smoothing does not effectively reduce the error, either for the L1-only signal or the dual-frequency one

To identify the problem we investigated the ranging errors of several satellites
Non-smoothed L1-only signal

Features of the dominant error:
• Fast variant
• Highly correlated across satellites
Non-smoothed Dual-freq signal

Features of the dominant error:
- Fast variant
- Highly correlated across satellites
Receiver Clock Error

- The fast-changing receiver clock error is the dominant error term
- The receiver clock error variations are identical across all satellites
- To clearly identify the desired error characteristics, the receiver clock errors need to be better estimated
- The airborne receiver clock error is estimated by averaging the measurement errors at each epoch
  - previously assumed smoothly varying clock over several hundred seconds

![Diagram]

Airborne Receiver Clock error

Remove the airborne carrier measurement cycle slips $\phi_{air}$

Averaging the carrier measurement errors across all the SV at each time epoch $b_{air}$
On board receiver clock error
Receiver Clock Error Estimate Result

Ground receiver clock error

![Graph showing Receiver Clock Error Estimate Result]

- **Time since app starts [sec]**
- **Receiver Clock Error [m]**

Legend:
- **Airborne receiver clock error**
- **Ground receiver clock error**
Error Results Validation

WAAS-corrected ground receiver ranging error: 95% are within ±0.55m.
WAAS PAN Report, Sep 2006: 95% error at Atlanta GA are within ±1.4m.

Data Duration: 6 minutes
All Satellites
Airborne Code Measurement Error

PRN 16 WAAS-corrected code meas.

Dual-freq signal noise is more than twice of the L1-only noise before smoothing
Carrier smoothing works effectively and the two signal noises are comparable

- High-frequency oscillation caused by WAAS corrections
- Still noticeable low-frequency error remains
Airborne Error Results

WAAS corrected ranging errors in approach 4

Non-smoothed L1 code error distribution

Non-smoothed dual-freq code error distribution

95% of Non-smoothed L1-only errors are within ±0.7m
95% of Non-smoothed dual-freq errors are within ±1.3m

Significant noise increase by dual-freq combination, but still less than expected
Airborne Error Results

WAAS corrected ranging errors in approach 4

95% of Smoothed L1-only errors are within ±0.6m (±0.7m)
95% of Smoothed dual-freq errors are within ±0.8m (±1.3m)

Carrier smoothing works effectively, especially for dual-freq signals
Comparable noise level after carrier smoothing
Findings

After exclude the receiver clock error:

- Dual-freq meas. combination greatly increases the signal noise before the smoothing
- The errors of both the L1 and dual-frequency signals are effectively mitigated by the carrier smoothing
- The noise levels of the L1 and dual-frequency signals are comparable after smoothing
Conclusions and Future Works

- The high rate of on-board receiver clock variation makes identification of measurement errors more difficult on flight test data

- A GPS receiver clock error estimation method is developed and its effectiveness is validated

- The ranging error noises of the two signals are similar after the carrier smoothing
  - May still be other error terms present obscuring desired error terms

- The future work will include clearly understand and identify all the error sources

- The future work will include the protection level calculations with better understanding of the error characteristics
Q & A
Thank you