GNSS Measurements Update

GNSS Raw Measurements from Android Phones

GSA Raw Measurements Workshop, Prague, 30 May 2018

v1.02

Frank van Diggelen
Google
What if we had one meter accuracy in phones?

Lane-level vehicle navigation

What’s the fastest route using carpool lanes?

Pedestrian navigation

Which side of the road am I?
What if we had centimeter accuracy from a phone?

GPS signal is a tape measure, With tick-marks labeled every 300m

You may know this as: “Differential GPS” “PPP” or “RTK”

Reference

GPS

Dual Frequency ...

Today all smartphone GPS/GNSS is on one frequency band: L1. L5 is a new frequency band supported by these GNSS systems: GPS, Galileo, BeiDou, QZSS, IRNSS.

Second frequency ⇒ faster convergence to carrier-phase accuracy.
### Sample applications ... 

<table>
<thead>
<tr>
<th>Research</th>
<th>Education</th>
<th>Accuracy</th>
<th>Crowd-sourced</th>
<th>Testing</th>
<th>Consumer</th>
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<tr>
<td>Atmosphere</td>
<td>GNSS</td>
<td>D-GNSS</td>
<td>Jammer detection</td>
<td>Monitoring:</td>
<td>Sports</td>
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<td>Iono</td>
<td>RF</td>
<td>RTK/PPP</td>
<td>Weather</td>
<td>Data</td>
<td>Golf</td>
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<tr>
<td>Tropo</td>
<td>Sig Processing</td>
<td>GIS</td>
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<td>Accuracy</td>
<td>Drones</td>
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<td>NMA (Auth.)</td>
<td>Orbits</td>
<td>Surveying</td>
<td></td>
<td>Antenna patterns</td>
<td>Mapping</td>
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<td></td>
<td></td>
<td></td>
<td>Rx Clock</td>
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<td>Walking Nav</td>
</tr>
</tbody>
</table>

- Sports
- Golf
- Drones
- Mapping
- Walking Nav
- Geocaching
Measurements, Tools and Analysis

1. Raw GNSS Measurements
2. Logging and Analysis Tools
3. What’s new in 2018
4. Hands-on exercises
5. Future: apps and research
Location APIs, Measurement APIs

aka Google Play Services
Most Android phones have this (not China)

Location APIs, android.gms.location
- Places
- Geofencing
- Fused Location Provider (FLP)
- Fit
- Activity Recognition
- Nearby

Measurement/Sensor APIs, in android.location
- Location
- GnssMeasurement
- GnssClock

All Android phones have this

GNSS Raw Measurements
All phones with:
GNSS chips build date ≥ 2016
OS ≥ Android N (Nougat)
Table: Which phones have GNSS Raw Measurements:

<table>
<thead>
<tr>
<th>Model</th>
<th>Android version</th>
<th>Automatic Gain Control</th>
<th>Navigation messages</th>
<th>Accumulated delta range</th>
<th>HW clock</th>
<th>Global systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTC U11 Plus</td>
<td>8.0</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>GPS, GLONASS</td>
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<td>GPS, GLONASS</td>
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<tr>
<td>Huawei Mate 10</td>
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<td>yes</td>
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<td>GPS, GLONASS</td>
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<tr>
<td>Huawei Mate 10 Pro</td>
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<td>yes</td>
<td>yes</td>
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<td>GPS, GLONASS, QZSS</td>
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<tr>
<td>Google Pixel 2 XL</td>
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<td>yes</td>
<td>no</td>
<td>no</td>
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<td>GPS, GLONASS, GALILEO, Beidou, QZSS</td>
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<tr>
<td>Google Pixel 2</td>
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<tr>
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<tr>
<td>Samsung Note 8 (Exynos)</td>
<td>7.1</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>GPS, GLONASS, GALILEO, Beidou</td>
</tr>
<tr>
<td>Samsung Note 8 (QCOM)</td>
<td>7.1</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>GPS, GLONASS, GALILEO, Beidou</td>
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<tr>
<td>LG V30</td>
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<td>no</td>
<td>no</td>
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<td>Moto X4 2017</td>
<td>7.1</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>GPS, GLONASS</td>
</tr>
</tbody>
</table>

Essential PH-1 7.1 no no no yes GPS, GLONASS
Moto Z2 7.1 no no no no yes GPS, GLONASS
HTC U11 7.1 no no no yes GPS, GLONASS
OPPO R11 7.1 no no no yes GPS, GLONASS
Huawei Honor 9 7.0 no yes yes yes GPS, GLONASS
Samsung S8 (Exynos) 7.0 no no yes yes GPS, GLONASS
Samsung S8 (QCOM) 7.0 no no no no yes GPS, GLONASS
Huawei P10 7.0 no yes yes yes GPS, GLONASS, GALILEO, Beidou, QZSS
Huawei P10 Lite 7.0 no no no yes yes GPS, GLONASS
Huawei Honor 8 7.0 no no yes yes yes GPS, GLONASS, Beidou
Huawei Mate 9 7.0 no no yes yes yes GPS, GLONASS, Beidou
Huawei P9 7.0 no no yes yes yes GPS, GLONASS, Beidou
Google Pixel XL 7.0 no no no no yes GPS
Google Pixel 7.0 no no no no yes GPS
Nexus 6P 7.0 no no no yes GPS
Nexus 5X 7.0 no no no yes GPS
Nexus 9 (non cellular version) 7.1 no yes yes yes GPS, GLONASS
Logging and Analysis Tools

GNSS Logger

GNSS Analysis
Logging the raw data on your phone:

1,

2,

3,

4.
Logged Data is stored locally, on the phone:
What’s new in 2018

Phone:
- Duty Cycling control
- Analysis on phone

Desktop
- L5/E5
- Mission Planning
- C/No comparison of different phones
- Error analysis for moving receiver
- Smoothed and Raw pseudoranges
- Log of derived data
- Iono & Tropo control
Duty cycling control,
For continuous carrier phase

In Android P:

<table>
<thead>
<tr>
<th>developer option</th>
<th>Full GNSS, track all available GNSS, with no duty cycling</th>
</tr>
</thead>
</table>

Force full GNSS measurements
Track all GNSS constellations and frequencies with no duty cycling
Analysis on Android
On the phone
Minimum C/No with 0 dBi RHCP antenna with 2dB Front End Noise Figure

<table>
<thead>
<tr>
<th></th>
<th>GPS (dB.Hz)</th>
<th>GAL (dB.Hz)</th>
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<tbody>
<tr>
<td>L1/E1</td>
<td>45.5</td>
<td>47</td>
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<tr>
<td>L5/E5a (I + Q)</td>
<td>49</td>
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<td>L5/E5a (I only)</td>
<td>46</td>
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</table>

Simulated measurement data to illustrate functionality of tools

From ICDs for GPS and Galileo

Antenna/filter loss at L5

mean(L5-L1) = -10.0 dB
Mission Planning

New feature: see where all the GNSS satellites are, at any time, from any place
C/No comparison from different phones
Measurement error for moving receiver

**Reference PVT**

- **Stationary Receiver:**
  - Lat (deg): 0.000000
  - Lon (deg): 0.000000
  - Alt (m): 0.00

- **Moving Receiver:**
  - NMEA File: 2017_03_06_sanfrancisco_truth.nmea

**Additional Options**

- Log File: gps_log_2017_03_06_sanfrancisco_L1L5.txt
- Directory: ~/Desktop/GnssAnalysisFiles/driving/
- Start UTC: yyyy mm dd hh mm ss.s
- End UTC: yyyy mm dd hh mm ss.s
- Iono: 
- Tropo: 
- Manual
- WLS
- NMEA
Plots from raw and smoothed pseudoranges

Similarly for WLS (Weighted Least Squares) position plots
Log file of derived data

<table>
<thead>
<tr>
<th>Raw</th>
<th>Elapsed Realtime</th>
<th>TimeNanos</th>
<th>FullBiasNanos</th>
<th>BiasNanos</th>
<th>BiasUncertaintyNanos</th>
<th>DriftNanosPerSec</th>
<th>DriftUncertaintyNanos</th>
<th>HardwareClockId</th>
<th>Svid</th>
<th>State</th>
<th>ReceivedSvTimeNanos</th>
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<td>72077039000000</td>
<td>-1151285108458</td>
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<td>29.0496824</td>
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<td>0.725224775</td>
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<td>15</td>
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<tr>
<th>MEAS</th>
<th>TimeNanos</th>
<th>Svid</th>
<th>CarrierFrequency</th>
<th>Cn0DbHz</th>
<th>AzDeg</th>
<th>ElDeg</th>
<th>RawPrM</th>
<th>RawPrUncM</th>
<th>RawPrErrorM</th>
<th>SmPrM</th>
<th>SmP</th>
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<td>33.5</td>
<td>63.7</td>
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<td>15754200000</td>
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<td>314.554</td>
<td>41.623</td>
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<td>216590986.60</td>
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<td>15734200000</td>
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<td>55.133</td>
<td>25.21</td>
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<td>1.799</td>
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<td>15734200000</td>
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<td>4.197</td>
<td>-7.244</td>
<td>24647316.64</td>
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</tbody>
</table>
Iono & Tropo control
Hands-on exercises

1. .../GnssAnalysisFiles/demofiles/
   ○ The demo log file you downloaded with the desktop app
   ○ We will use this to learn the capabilities of the analysis tools

2. .../GnssAnalysisFiles/driving/
   ○ GPS dual-frequency log file with ground-truth nmea
   ○ Use this to analyze reflections in urban canyons

3. .../GnssAnalysisFiles/ionotropodemo/
   ○ GNSS log file, stationary, at a known position, open sky
   ○ Example of how to analyze iono and tropo errors.
Exercise #1  

.../GnssAnalysisFiles/demofiles/
Download log files for the following exercises

https://sites.google.com/corp/view/gnsstutorial

Sample log files to run with GnssAnalysisApp

These zip files have GnssLogger log files with ephemeris for you to process with the GnssAnalysisApp

- **driving** (log file, driving, GPS, L1L5, with truth nmea)
- **ionotropodemo** (two log files, GNSS and GPS-only, stationary with true position in readme.txt)
### Exercise #2

.../GnssAnalysisFiles/driving/

<table>
<thead>
<tr>
<th>GNSS Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Log File</strong></td>
</tr>
<tr>
<td><strong>Directory</strong></td>
</tr>
<tr>
<td><strong>Start UTC</strong></td>
</tr>
<tr>
<td><strong>End UTC</strong></td>
</tr>
<tr>
<td><strong>Iono</strong></td>
</tr>
<tr>
<td><strong>Tropo</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reference PVT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stationary Receiver:</strong> Lat (deg)</td>
</tr>
<tr>
<td><strong>Moving Receiver:</strong> NMEA File:</td>
</tr>
</tbody>
</table>
Analysis example, driving into San Francisco:
Analysis example, driving into San Francisco:

What happened with satellite G22?

Low satellite

PR Error 50m

-10 dB
Exercise #3  .../GnssAnalysisFiles/ionotropodemo/

1. Use true position for Reference PVT
2. Select highest satellites to use for clock bias computation (CustomParam.txt)
3. Remove iono and tropo model from analysis

Then error plot will show all errors relative to the highest satellites.
How to get true position from Google Earth (1)

Preferences …

Show Lat/Long
Decimal Degrees

Units of Measurement
Meters, Kilometers

Terrain
Use high quality terrain
Use 3D imagery
How to get true position from Google Earth (2)

hG = height above Geoid, from Google Earth 3D Buildings, 20m
hS = height of stand = 1m
dE = -32, Ellipsoid - Geoid

hE = hG+hS+dE = 20+1-32 = -11 m.

Rooftop true position: 37.421568, -122.085429, -11m
%Currently supported:
%param.losSvid = list of svid to use for computing clock (Bc and BcDot)
%template for losSvid.Svid: must have .FreqBand, .Constellation, .Id
Svid1.Id = 32;
Svid1.FreqBand = GnssConstants.L1_BAND;
Svid1(Constellation = GnssConstants.GNSS_CONSTELLACTION_GPS;
param.losSvid.Svids = {Svid1}; %pack in a cell array

You edit these lines to choose the reference satellite(s) you want.

And place this txt file in the same directory as your log file.
Analyzing, errors: \( \text{iono} + \text{tropo} + \text{SIS}^1 \)

\(^1\text{SIS errors = Signal In Space errors = errors after applying broadcast ephemeris and clock values} \)
Future: examples of apps and research

1. Jamming detection
2. Carrier-phase PVT
3. GNSS system monitor
4. Signal analysis (iono, tropo, SIS, multipath, radio noise)
1) Jamming detection

Sample data collected live on an Android O test device

![Graph showing AGC levels](image)

- Alternating values? AGC levels are specific to the hardware, so you can't read too much into the details, but the trends are useful.

- Jammer source = operating microwave oven
- Device in front
- Device by the door edge

Measurements over time (~10-20 measurements, GPS & GLONASS, 40 seconds elapsed)
2) Carrier phase = AccumulatedDeltaRange

ADR is continuous only when clock is continuous, and there is no duty cycling.
Apps for high-accuracy GPS

L1 “PPP” <1m accuracy after a few minutes

Public sources for code libraries and reference networks:
www.rtklib.org, RTKLIB: An Open Source Program Package for GNSS Positioning
www.igs.org, International GNSS Service

PPP = Precise Point Positioning

PPP Wizlite, from CNES
3) Decoded Nav data, in Gnslogger:

And in log file:

```
# # Header Description: #
# Version: 1.4.0.0, Platform: N #
# Nav,Svid,Type,Status,MessageId,Sub-messageId,Data(Bytes) #
Nav,2,257,1,0,3,34,-61,121,25,12,-108,107,35,0,33,-42,115,35,46,-77,-78,63,-5,-55,-81,29,76,25,-91,8,-23,106,-113
Nav,12,257,1,0,3,34,-61,121,25,12,-108,107,35,63,-5,2,54,6,-27,120,-7,63,-13,10,55,22,-69,6,-108,6,-99,-120,59,9,
Nav,25,257,1,0,3,34,-61,121,25,12,-108,107,35,63,-8,-63,106,63,25,3,-49,63,-6,-55,-21,55,-49,35,111,6,-63,-56,18,
Nav,98,769,1,0,1,8,87,-128,22,-95,96,-81,-109,-100,30,-104
```

Decimal equivalent of each byte, for example: 0b00111111 = 63
4) Signal analysis: iono, tropo, SIS, multipath, and radio noise:

<table>
<thead>
<tr>
<th>Average C/No</th>
<th>σ (pseudorange errors)</th>
</tr>
</thead>
<tbody>
<tr>
<td>46 dB.Hz</td>
<td>5.4 m</td>
</tr>
<tr>
<td>37 dB.Hz</td>
<td>9.2 m</td>
</tr>
<tr>
<td>30 dB.Hz</td>
<td>18.2 m</td>
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</table>
Summary

- Get raw measurements from Android phones
- Details and software at https://g.co/GnssTools
- Much analysis you can do with the tools directly
- Save derived data, and do further analysis with it
- Pursue research, teaching, testing and app development based on these measurements
End,

Thank you.